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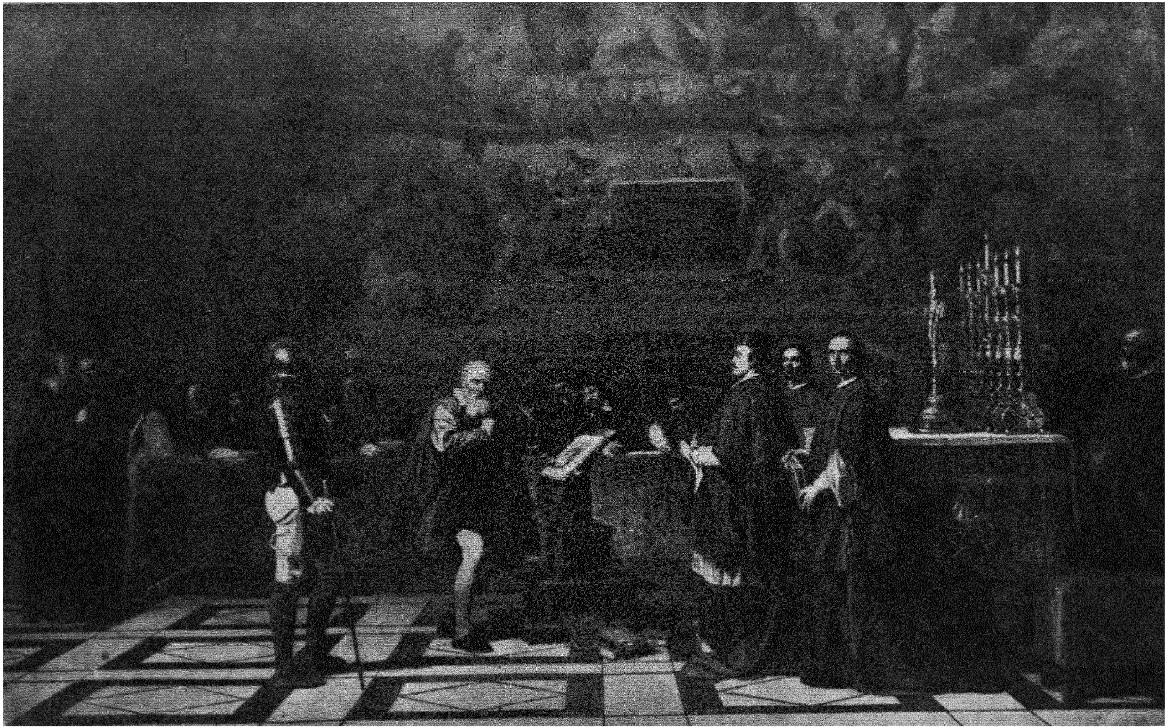
GENERAL SCIENCE



Courtesy of Rischgitz Art Studios

Galileo before the Papal Tribunal
[*By Robert Fleury*]

GENERAL SCIENCE

BY

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PREFACE

GENERAL Science as now taught in our Secondary Schools covers such a wide field that the selection of subject matter is not an easy task. The authors have been guided in this choice partly by their own experience, partly by the requirements of the School Certificate examinations and partly by the publications on the teaching of this subject. Sufficient subject matter is included to meet the needs of any of the School Certificate examinations in General Science.

It is believed that a single text-book written to meet the requirements for these examinations will not only give definition to the course, but also help to co-ordinate the various branches of the subject.

The authors are under a deep debt of gratitude to their colleague, Mr. J. E. Filby, and to Mrs. J. N. Britton for their work in the laborious task of preparing the diagrams. They also gratefully recognize the courtesy of many firms for allowing them to reproduce photographs, and individual acknowledgments are given below the illustrations. Kind permission to use the diagrams mentioned on the next page has been given by the authors and publishers of the books named.

In the work of preparing the book valuable assistance has been given by Mr. J. N. Britton and Mr. H. E. Wilmott, of the House of John Murray, and the authors are particularly glad to acknowledge their help.

Mr. O. H. Latter, formerly Senior Science Master at Charterhouse, was kind enough to read the proofs of the biology section and gave a great deal of valuable advice, for which grateful thanks are due.

The questions at the end of the book are selected from recent School Certificate examination papers and are printed by the kind permission of the following examining bodies: The Cambridge Local and the Oxford Local Syndicates, the Oxford and Cambridge Examination Board, the University of London Matriculation Board, the Joint Matriculation Board of the Northern Universities.

A. S.
J. W. C.

July 1939.

ACKNOWLEDGMENTS

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CHAPTER I

HEAT: EXPANSION

THE use and control of fire marks an important stage in the early history of mankind. Animals eat their food raw and make no use of fire, indeed most creatures are afraid of it. Primitive man first used it to cook his food and to give him warmth, but as time progressed fire became more and more under man's control until to-day the heat obtained from fires and from other sources serves a great variety of purposes. Many of the changes which take place in substances are produced by heat, one of the simplest of which is the effect of heat expansion.

Most things when heated expand and so increase all their measurements, but when allowed to cool they contract and return

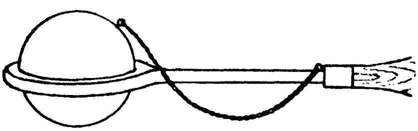


FIG. 1

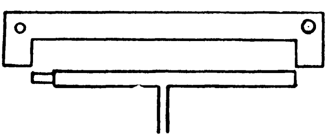


FIG. 2

to their original size. The increase in size, although very small and not usually noticeable in the case of solids, can easily be demonstrated. A ball of metal, Fig. 1, when cold just passes through the ring, but when it is heated it expands and is then too big to pass. On cooling it returns to its normal size and again will pass through the ring. The bar of metal, Fig. 2, fits tightly between the jaws of the gauge when cold, but it is too long to do so after being heated although it fits again when cooled.

Different metals do not expand to the same extent, as can be shown by using a compound bar made of a strip of iron and one of brass, Fig. 3. When this is heated it becomes bent, the brass strip being on the outer side of the curve. Brass expands more than the iron so that the bar takes a curved form to accommodate the expansion.

Considerable force is exerted in both the expansion and contraction of solids if the body concerned is not free to move. For example, an iron bar, Fig. 4, passes at each end through the sup-

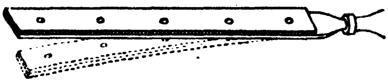


FIG. 3

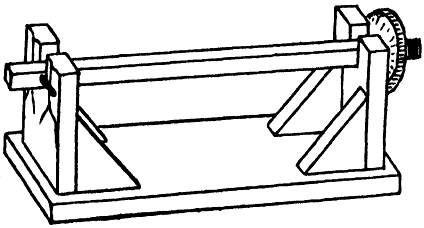


FIG. 4

ports of a strong iron stand. At one end it is held fast by a small cast-iron rod (blackened in the figure) which bears against the two projections from the support. At the other end the bar is screwed up so that it is tightly fixed between the supports. The bar is heated with a bunsen and the screw is tightened to take up the increase in length due to expansion. A wet duster is placed over the apparatus and this cools the bar rapidly. The bar contracts, the force of contraction is great enough to break the small cast-iron rod.

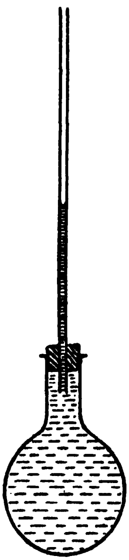


FIG. 5

The Expansion of Liquids.—The flask, Fig. 5, is filled with coloured water so that about an inch or so of the vertical tube is also full. It is heated and the water-level in the tube rises a few inches owing to the expansion of the water on heating. Other liquids behave in a similar way. (The glass also expands, so increasing the volume of the flask, but the effect is relatively small since glass expands much less than do liquids.)

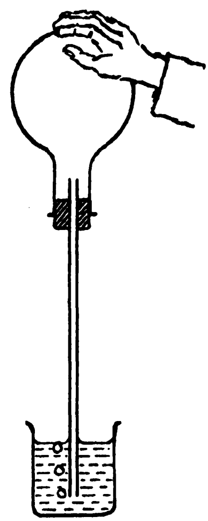


FIG. 6

Expansion of Gases.—A flask, fitted with a stopper carrying a long tube, Fig. 6, is inverted with the tube dipping into water. The air in the flask is heated by placing the hand on the flask, it expands and some of it is forced out of the tube and rises as

bubbles through the water. When the hand is removed the air contracts and the water rises a considerable way up the tube. Most of the air in the flask can be driven out, by heating it with a bunsen burner. (All gases expand equally when heated under the same conditions and the amount of expansion is much greater than that of liquids or solids.)

Thermometry.—Thermometers are instruments made to measure temperature i.e. the degree of hotness or coldness. They are based on the principle that liquids expand in volume when heated, and contract when cooled. Most common thermometers are filled with mercury, a liquid which does not freeze until it is cooled to a relatively low temperature (− 39° C.) or boil unless heated to a very high one (357° C.) and so it can be used to indicate a large range of temperatures. Moreover, it quickly registers changes in temperature, is readily seen and does not wet the sides of the glass tube. Alcohol, which has been coloured red, is sometimes used instead of mercury for it has a lower freezing-point than mercury.

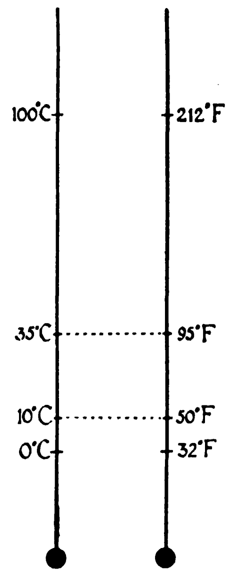


FIG. 7

The thermometer has markings on it which form an evenly divided scale. Two of these are of special importance since they mark two "fixed" points. Pure water always boils at a definite temperature (at standard pressure); pure ice also melts at a definite temperature. These two temperatures are taken as the "fixed points." The temperature of melting ice is called 0° C. on the Centigrade thermometer and that of boiling water 100° C., and the scale is divided into 100 equal divisions. These two temperatures are marked 32° F. and 212° F. respectively on the Fahrenheit thermometer and the distance between them is divided into 180 equal divisions. The Centigrade thermometer is used in most scientific work while the Fahrenheit is used in industry and in common everyday use in England. It is a simple matter of arithmetic to convert one measurement into the other, particularly if some such diagram as Fig. 7 is remembered, since 0° C. $\equiv$ 32° F. and one Centigrade division $\equiv \frac{180}{100} = \frac{9}{5}$ Fahrenheit divisions.

(1) Convert 95° F. to degrees Centigrade.

95° F. is (95 − 32) i.e. 63 divisions above zero on Fahrenheit scale

$$= \frac{63 \times 5}{9} = 35 \quad ,, \quad ,, \quad ,, \quad ,, \text{ Centigrade } ,,$$

$$\therefore \text{ Temperature} = 35^\circ \text{ C.}$$

(2) Convert 10° C. to degrees Fahrenheit.

10° C. is $10 \times \frac{9}{5}$, i.e. 18 divisions above zero on Fahrenheit scale

$$\therefore \text{ Temperature} = 18 + 32 = 50^\circ \text{ F.}$$

The accuracy of a thermometer can be verified by placing the bulb in pure clean melting ice and leaving it there for a few minutes. If the thermometer is accurate the mercury-level will be at the division 0° C. (or 32° F.). The upper fixed point is verified by placing the bulb of the thermometer in steam so that as much of the stem as possible is also surrounded by steam. After a few minutes the mercury should have just reached the markings 100° C. (or 212° F.).

The Clinical Thermometer.—The blood temperature of a healthy person is constant 98·4 F. A temperature a degree or so above or below this indicates an abnormal condition. In

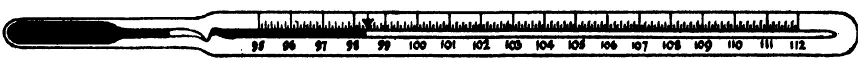


Fig. 8

fever the temperature rises to more than 100° F. and a patient is dangerously ill if his temperature is 104° F. The clinical thermometer (Fig. 8) used by doctors must consequently register quite small differences in temperature, hence each degree-division is subdivided into fifths of a degree. It is put under the armpit or tongue of the patient, and left there for a few minutes. The heat of the body causes the mercury to expand and force its way past the constriction. The thermometer is then withdrawn and although the mercury then contracts, since the air of the room is colder than the body, that in the tube cannot force its way back through the constriction (there being no force pushing on it). Hence the temperature of the body can be read, after which the thermometer is shaken, so forcing the mercury through the constriction and the instrument is again ready for use.

Maximum and Minimum Thermometer.—Fig. 9 shows a Six's thermometer which records the maximum and minimum temperatures at the same time and is used for taking weather

records. Bulb A contains a little alcohol and alcohol vapour, bulb B is full of liquid alcohol. The blackened part contains mercury, on the top of each column of which is a small steel dumb-bell with a small spring attached (see inset). When the temperature increases the alcohol in B expands and pushes the mercury down in C and up the limb in D. This pushes the dumb-bell up the tube, where it stops at the maximum temperature which is reached. When the temperature falls the alcohol in B contracts and the mercury in C rises up in the tube and carries the dumb-bell with it. The dumb-bell in C therefore registers the minimum temperature attained. The thermometer is re-set by drawing the pieces of steel to the top of the columns using a magnet.

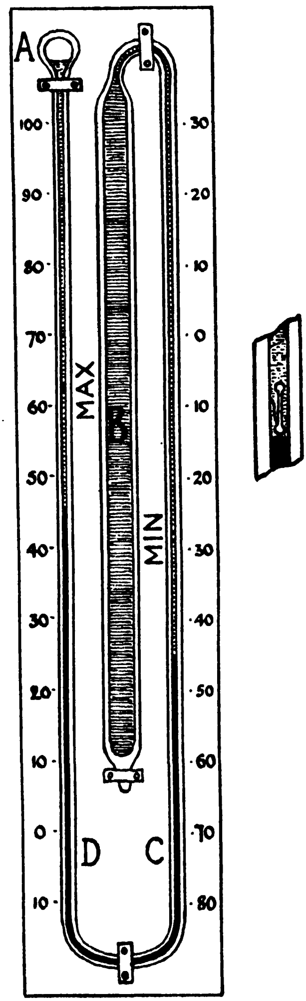


FIG. 9

Heat-Expansion in Everyday Life.—The difference in temperature between summer and winter is considerable even in an island like ours; on large continents such as North America, Europe and Asia it is much greater. Allowance has to be made, in all countries, for the consequences arising from this temperature-difference. Some idea, for example, of the expansion of metallic objects is obtained from a knowledge of the coefficient of expansion of a metal such as steel. This coefficient expresses the increase in unit length of the steel when it is heated 1° C. It is 0·000012. Therefore each foot of steel increases by 0·000012 feet for each 1° C. it is heated. This seems a very small increase and it is small when only a one-foot length is considered. But consider an extreme case such as the Sidney Bridge, which is made of steel, the central span being 1,650 feet long. The difference between summer and winter temperatures is about 40° C. and therefore the steel will expand about $1{,}650 \times 40 \times 0{\cdot}000012$ feet, that is about $9\frac{1}{2}$ inches.

Unless allowance is made for this the iron girders will buckle under the force of expansion. Smaller lengths of iron, and other metals, do not, of course, have such an expansion but it is big enough to cause allowance to be specially made and some instances will now be mentioned. The iron bars on the top of a gas-cooker are always loosely fitted; telegraph wires sag in summer owing to their increased length; long

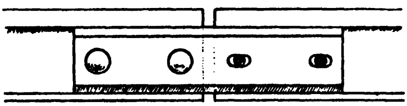


FIG. 10

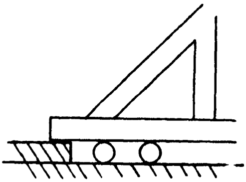


FIG. 11

iron pipes conveying hot water have expansion joints of various kinds. Railway-lines are laid with a gap between them, but, for obvious reasons, they must be joined together. This is done by the use of "fish plates," Fig. 10. In each plate are four oval-shaped holes (two of which are shown empty) and the rails are bolted fast through the holes. As the rail expands or contracts the bolts slide along the oval holes. The girders of long iron railway bridges are not securely fixed at each end. In some cases the ends are laid on rollers (Fig. 11), over which the girder slides as it expands or contracts.

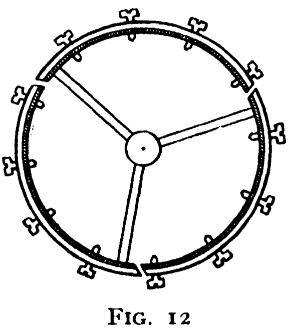


FIG. 12

The balance wheel of a watch is affected by temperature changes in two ways. Not only does the balance wheel expand in hot weather but the spring also becomes slightly weaker. Both these changes have the effect of increasing the time of swing of the wheel. In the best watches, in order to compensate for this, the wheel rim is made of a compound strip of brass and iron with the brass on the outside and is made in sections (Fig. 12). One end of each section is fixed to the hub by a rib which expands outwards in hot weather while the rim is bent inwards, so supplying the necessary compensation, not only for the expansion of the wheel but also for the weakening of the spring.

Thick glass is liable to break when heated in, say, the oven. The outer surface becomes hot, but since glass is a bad conductor of heat

the inner surface does not immediately reach the same temperature. Hence the outer surface expands at a greater rate than the inner and the glass cracks. Modern ovenware is made of a special glass, silica glass, which expands very much less than ordinary glass and so it can be heated with safety.

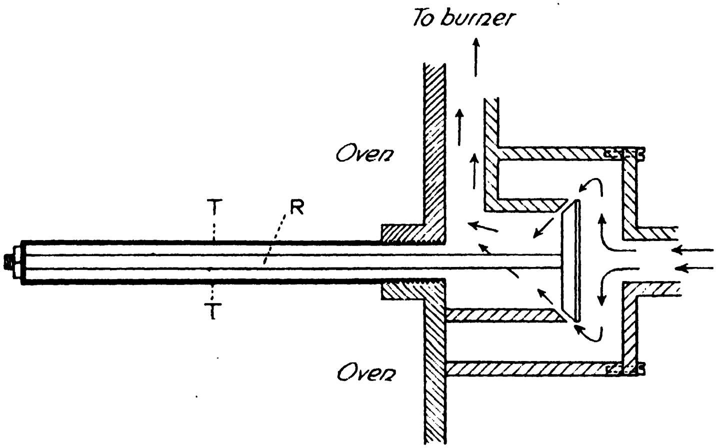


FIG. 13

Some of the effects due to expansion are rendered negligible by the use of a special alloy called invar which is made of steel and nickel. This alloy neither expands nor contracts appreciably when subjected to temperature changes. Thus when the rod of a pendulum is made of invar it keeps a constant length.

A gas oven can be maintained at a definite temperature by regulating automatically the supply of gas. This is done by means of a thermostat (Fig. 13). As the temperature of the oven rises the outer brass tube T, which is in the oven, expands and carries the rod R inwards with it. This rod is made of invar and does not alter its length. The valve head, being attached to R, moves along with the rod and reduces the size of the opening through which the gas enters the burner. Finally, when the required temperature is reached just sufficient gas passes to maintain it. The temperature can be regulated by adjusting the distance which the valve has to move.

Use is frequently made of the contraction of a metal on cooling. Thus when two iron plates are to be riveted together they are first placed to overlap each other and a hole is drilled through both of

them. A red-hot iron rivet is put through the hole and the underside is hammered flat (Fig. 14). When it cools and contracts it draws the plates closer together. The iron rim of a cart-wheel, or the flange of an iron wheel, is first heated and then put on. When it is hot it just fits, but only just. On cooling it contracts and grips the wheel tightly. The walls of a building sometimes lean outwards owing to the weight of the roof. They can be pulled into the perpendicular by the force exerted when a hot iron bar contracts. A piece of metal shaped like a letter S or an X is put against each of the outer walls and the two are connected by a long iron rod going across the width of the building. Each piece is screwed to this rod. The rod is then heated and expands. The end pieces are then screwed up tightly and the iron rod is allowed to cool. As it does so the force of contraction is enormous and the two end pieces pull the walls straight. Owing to their shape the pressure on the end pieces is distributed over a great area of the outer walls.

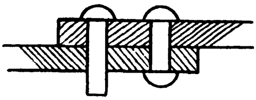


FIG. 14

CHAPTER II

MOVEMENT: FORCES

A STUDY of movement and all the conditions affecting it is of great practical value as well as of real interest. To most of us there is a fascination in the idea of rapid movement which is reflected in the interest shown in new speed records. The meaning of the word speed can be illustrated by considering a motor-car travelling along a road. When the speedometer needle, Fig. 15, remains steady the car is moving at a constant or uniform speed and is covering the same distance in each interval of time, such as a second. Speed is the distance travelled in unit time and is usually expressed in miles per hour (m.p.h.) or in feet per second (ft./sec.).

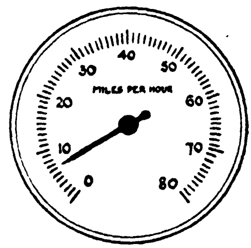


FIG 15.

A speed of 30 m.p.h. is the same as one of $\frac{30 \times 5{,}280}{60 \times 60} = 44$ ft./sec. and the distance travelled can be found by multiplying speed by time: thus

$$\text{Distance} = \text{speed} \times \text{time}.$$

Acceleration.—More often than not speeds are not constant or uniform; usually the speed of a car varies frequently, particularly in towns. It is usual to talk of the average speed for a journey and this is obtained by dividing the total distance travelled by the time taken. Allowing for a little time-lag the needle of a speedometer registers the actual speed and shows by its movements when the car increases its speed (accelerates) and also when it decreases its speed (decelerates). Thus if it shows the car is travelling at 10 m.p.h. and a minute later at 28 m.p.h. the increase in speed in a minute is 18 m.p.h. If the increase in speed is regular, as will be shown by a steady upward movement of the needle, the acceleration is said to be constant. In this example it is 18 m.p.h.

per minute, which equals $\frac{18}{60}$ m.p.h. per second. But $\frac{18}{60}$ m.p.h. is equivalent to 0·44 ft. per sec. Hence the acceleration is 0·44 ft. per sec. per sec. The increase in speed under these conditions is given by multiplying the acceleration by the time during which it is taking place. Thus in 100 seconds the car increases its speed by $0{\cdot}44 \times 100 = 44$ ft. per sec. or 30 miles per hour.

Falling Bodies.—For centuries it was believed that a light body necessarily fell to the ground more slowly than a heavy one. This was stated to be so by Aristotle, a celebrated Greek philosopher, who lived more than 2,000 years ago. Until the sixteenth century his writings dominated opinions on natural phenomena. Indeed his writings were regarded as authoritative and anyone disputing his statements got into trouble with the Church. The study of science was entirely a bookish one based on Aristotle's works and not, as now, based on the results of experiments and observation. There were, however, a few who could not blindly accept Aristotle's opinions but rather trusted to their own senses and to their own ability to observe and to experiment. One such was the Italian, Galileo (1564–1642), who, for his beliefs, was brought before the Inquisition (see frontispiece).

Galileo dropped a cannon ball and a bullet simultaneously from the top of the leaning Tower of Pisa (180 feet high). Both reached the ground at the same time although the cannon ball of course was much heavier than the bullet. Yet we all know perfectly well that if a coin and a feather are dropped at the same time the coin will reach the ground much before the feather. Robert Boyle (*c.*1660) made clear the reason for this in his celebrated "guinea and feather" experiment. He exhausted all the air out of a long vertical tube and allowed the coin and feather to drop the full length of the tube. They kept together during their fall and reached the bottom of the tube at the same time. This showed that the air is ordinarily responsible for the difference in time taken by the coin and the feather in falling. It offers a greater resistance to the movement of the feather than to that of the coin and so the feather falls at a slower rate.

In the absence of "air resistance" objects not only take the same time to fall from the same height but also increase their speed at the same regular rate. They fall with the constant acceleration of 32 ft. per sec. per sec. An object falling in this way will, in three seconds, reach a speed of $3 \times 32 = 96$ ft. per sec. or more than 60 m.p.h. Light objects falling through the air after accelerating from

rest finally reach a steady speed because of the increasing effect of air resistance at high speeds. For example, a parachutist at first falls with a great acceleration, but when the parachute opens the air resistance is greatly increased so that by the time he is near to the earth he is usually moving at a fairly constant speed.

Turning Movements.—Many of the movements with which we are familiar are turning movements and are called rotations. The speed of rotation such as that of a wheel or motor is expressed in revolutions per minute (r.p.m.), e.g. a small electric motor may have a speed of 1,500 r.p.m. A rotation takes place about a fixed line or axis. Thus a wheel rotates about its axle and the earth spins about a central axis joining the two geographical poles.

The rotation of the earth about its axis provides the unit of measurement of time. On account of this movement the sun appears to revolve round the earth in the opposite direction to the rotation. The average time for the apparent movement is taken as twenty-four hours and this gives the length of the solar day. The stars appear to move round us more quickly than this, for the earth revolves round the sun once a year in the same direction that it rotates on its axis. The earth is like the kind of car on a merry-go-round which not only goes round with the whole machine but spins as well. The fair to anyone in the car appears to go round once for each turn and once for each spin when the two movements are in the same direction. Similarly the stars appear to go round $366\frac{1}{4}$ times a year, once due to the movement round the sun and $365\frac{1}{4}$ times due to the daily spin. A day reckoned from the movements of the stars, which is called a sidereal day, is therefore about $\frac{365}{366} \times 24$ hours or about four minutes less than the solar day.

The Pendulum.—The use of the pendulum for controlling the movement in clocks owed its introduction to Galileo. His investigations into pendulum movements are said to have started during a service in the cathedral at Pisa when he noticed the swinging of a lamp hung from the roof. Each swing appeared to take the same time, and he checked this from the beat of his pulse. He afterwards applied his discovery to the measuring of pulse rates, which in the absence of watches as we know them to-day must have been difficult. A simple pendulum consists of a small weight (the bob) hanging from a thin cord as shown in Fig. 16. When the bob is pulled a little to one side the pendulum swings, or vibrates. A vibration is a complete backward and forward movement and can be timed by observing the passage of the string in the same

direction past a mark such as the one A. It is found, by timing the vibrations by use of a stop-watch, that the time of each vibration is the same and does not depend on the weight of the bob or the extent of the swing (for small swings). If the bob is moved higher, so shortening the length of the pendulum, the time of vibration decreases and experiment shows that this time varies as the square root of the length of the pendulum.

A seconds pendulum has a length of about 39 inches, such a pendulum taking one second for one swing from side to side (the time of vibration is actually two seconds).

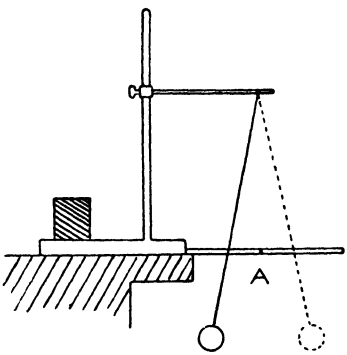


FIG. 16

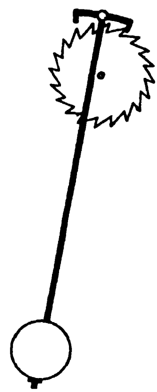


FIG. 17

Clocks.—In a clock the pendulum controls the movement of the hands by means of the escapement (Fig. 17). This usually consists of a cross bar at the top of the pendulum which at the end of each swing engages with one of the teeth of a wheel, this taking place first from one end of the bar and then from the other. The bar allows one tooth to escape from under it during each swing so that the pendulum controls the movement of the clockwork which drives the wheel and the hands connected to it. As the teeth strike the ends of the cross bar they also give slight impulses to the bar and so keep the pendulum swinging.

FORCES

In the ordinary actions of everyday life objects are moved by pushing and pulling them and it is much the same when they are moved mechanically. These pushes and pulls are forces and are

often called driving forces because of their power of producing and maintaining movement.

A train starts moving and gathers speed (or accelerates) because of the pull of the engine on it, but the engine also needs to pull on the train to keep it going even when its normal running speed has been attained. This is because there are certain resistances or oppositions to movement which have to be overcome in order to keep an object moving at a constant speed. Some consideration of these resistances will be given after dealing with the way in which forces can be measured.

Measurement of Forces.—Forces of all kinds can be measured in terms of weight. Thus the force exerted by a person in pulling out a spring balance has a magnitude equal to the number of pounds registered on the balance. Although most forces cannot be measured by this simple method they are all expressed in terms of pounds weight (or tons weight).

Besides having magnitude a force also has direction, e.g. a football starts to move in the direction of the force of the kick. A force also has a definite line of action and point of application on the object.

The Resistance due to Friction.—A book is much more easily pushed along a smooth surface such as a table-top than over a rough one, and much less force is required to push a planed wooden block over a smooth surface than to push a rough block over the same surface. There is evidently some resistance to this sliding type of movement which is greater the rougher one or both of the surfaces.

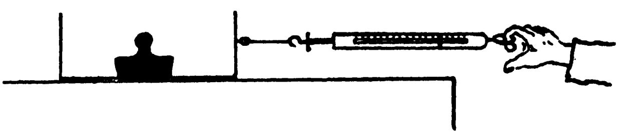


FIG. 18

This resistance is due to friction and its effects can be investigated by using a small wooden box and a spring balance (Fig. 18). The box remains at rest on a horizontal surface even when a slight pull is exerted, but as the pull is increased the box moves and the force necessary to move it steadily along, as registered on the balance, gives a measure of the resistance due to friction. When weights are added to the box the surfaces are pressed closer together and the resistance due to friction increases so that a greater force is

then required to move the box. The sliding friction between two surfaces increases with the roughness of each of them as well as with the force pressing the two surfaces together. It can be shown by mounting the box on wheels or rollers that less force is then needed to move it steadily along than when there is sliding movement. "Rolling" friction offers less resistance to movement than does sliding friction and it is therefore an advantage to mount vehicles on wheels. But although the rim of the wheel then rolls over the ground there is still sliding friction between the wheel and the axle. The resistance is considerably diminished by the use of ball bearings. These are shown in position in a bicycle wheel in Fig. 19. This figure should be compared with the one alongside it. It will be seen that the inner surface of the hub of the wheel

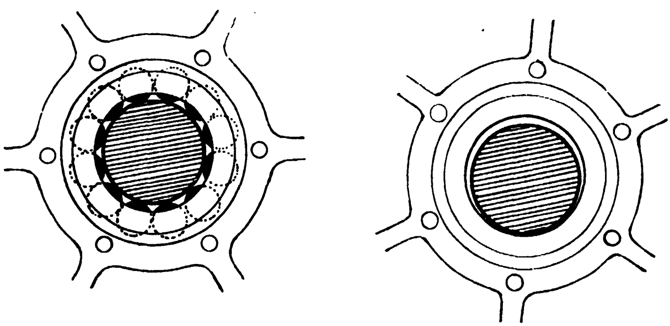


FIG. 19

slides over the axle at the point of contact when there are no ball bearings. When there are bearings, however, there is no sliding friction.

A layer of oil forms a smooth surface. In effect, in most well-lubricated machines sliding of the moving parts takes place between layers of oil and not between two metallic surfaces, so that when two oily surfaces slide over each other the effect of friction is much less than it would be if they were dry. Two dry surfaces soon get hot when they are rubbed together, indeed one of the earliest methods of making fire was to rub two dry sticks together as is still done by certain primitive tribes and we all realize that the hands get warm by rubbing them together. The heat produced may be enough to damage the machine but this is averted by the use of oil. Oil also minimizes the amount of wear of the materials where two surfaces move over each other.

Friction is not always a nuisance. Indeed, in many machines

it is often deliberately used to bring objects to rest. Thus a brake works by setting up a resistance between the brake linings (which have rough surfaces) and the moving parts and can be adjusted or controlled by altering the pressure of the brake blocks on the wheels.

Gravitational Resistance.—A force equal in magnitude to the weight of the object is needed to move an object vertically, but, in the absence of friction, much less force is needed to move it up an incline or gradient. The gradient is usually expressed in terms of rise against length along the incline. Thus gradient of 1 in 200 is one in which there is a rise of 1 foot for every 200 feet of length. The effect of a gradient on the force needed to move an object can be found by means of the apparatus in Fig. 20. When the roller is pulled steadily up the incline the force exerted is measured by the spring balance. Results of experiments show that the force needed to produce and maintain steady movement equals the weight of the roller multiplied by the gradient. An example from everyday life illustrates this: a train weighing 500 tons and running up an incline or gradient of 1 in 200 needs a driving force equal to $500 \times \frac{1}{200} = 2\frac{1}{2}$ tons to keep it going, in addition to the force needed to overcome friction and other resistances.

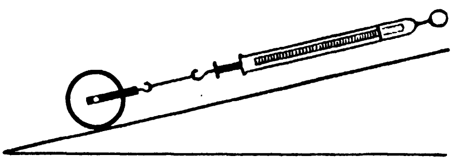
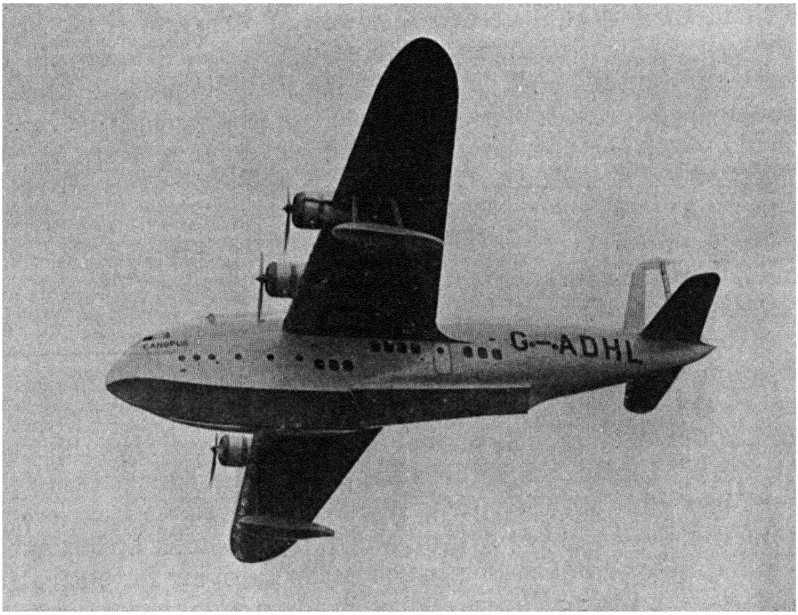


FIG. 20

(There is no direct resistance due to gravity in moving an object along a horizontal surface. When, however, there is friction the resistance due to it increases with increase of weight of the object, so that there is usually an indirect effect due to the weight owing to the pressure exerted by the object on the surface.)

Air Resistance.—The demand for speed in transport has brought air resistance much into the public eye. This resistance increases as the speed of the moving object increases and is one of the main considerations in the design of high-speed cars and trains and particularly in the design of aeroplanes (Fig. 21). An important part of the air resistance is the friction between the surface of the object moving and the air in contact with it. This is reduced by making the surface as smooth as possible and may be compared with ordinary friction between solid surfaces. Thus the wing surfaces of aeroplanes are made smooth and are even polished to reduce the resistance due to the frictional effects. Another part of the air

resistance is diminished by stream-lining and by having few, if any, projecting parts (see Fig. 23). The general idea underlying this is to enable movement to take place so that the air is dis-



Courtesy of "Flight"

FIG. 21

Imperial Airways Empire Flying-boat "Canopus" in Flight

turbed as little as possible as the object moves through it. The shape which best satisfies these conditions is shown in Fig. 22. It consists of a rounded front and a pointed back. This is the general shape used for airships and for parts of aeroplanes, including the struts. Why this shape is suitable can be seen by considering what happens if the object is at rest and

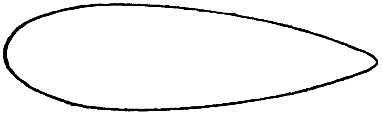


FIG. 22

the air is flowing past it. The air currents keep close to the surface and are not broken up into eddies, which cause loss of energy and increase the resistance to movement.

Resistance due to Inertia.—The force needed to start an object moving increases with the weight and the heavier the object the more slowly it starts when a constant force acts on it. A horse can start up a heavily loaded railway truck, though it takes some time to do so. The acceleration produced depends upon the force producing it, but the speed reached depends on the acceleration and the time. Consequently the speed attained depends on the force and the time during which it is acting. Most boys know that in kicking a ball there should be a good "follow through"

Courtesy of L.M.S. Railway

FIG. 23
The "Up" Coronation Scot

of the kick so that the force applied continues to act on the ball for as long a time as possible. All objects need some outside influence from other material things to start them moving and even to change either the speed or the direction of movement. This property, which is common to all material things, is called inertia, from a Greek word meaning lazy. The principle of inertia may be stated:

An object cannot alter its own state of rest or of uniform movement in a straight line; any such change requires some outside influence or force.

Other effects of inertia are well known—a person standing in a bus is jerked forward when the bus pulls up suddenly and parcels are then sometimes jerked off the luggage-rest. The person who is standing is moving forward with the speed of the bus. The bus is pulled up suddenly by the brakes and is brought to rest. The force set up by the brake does not act directly on the person, or on the parcels on the luggage-rack and they tend to continue their forward movement.

Work.—The word " work " in science has often much the same meaning as it has in common speech, but is used in a more precise way. Thus anyone raising a weight does a certain amount of work which is measured by the product of the weight and the vertical distance it is lifted. When a weight of 60 lb. is lifted two feet the work done is said to be $60 \times 2 = 120$ ft. lb. In this example the work has been done against the force of gravity.

There are the other resisting forces besides gravity, such as friction and air resistance, and work has also to be done when objects are moved against their opposition. But no matter what the resistance is, the work done is always equal to the force exerted, multiplied by the distance through which the object is moved in the direction of the force.

The term " horse-power " was introduced by James Watt so that he could compare the rate of working of his engines with that of a horse. It was used as a " selling point " so that people who were thinking of using his engines to displace horses could realize what they were getting for their money. Watt stated that the rate of working of a horse was 33,000 ft. lb. per minute so that 1 h.p. = 33,000 ft. lb. per minute.

The horse-power developed by a modern stream-lined engine is enormous. Thus an engine of the Princess Coronation Class (see Fig. 23) has a tractive effort of 40,000 lb., and when it is travelling at 5,000 feet per minute (approximately 60 miles per hour) the work it is doing each minute is $40{,}000 \times 5{,}000$ ft. lb. The horse-power of the engine moving under these conditions is $\frac{40{,}000 \times 5{,}000}{33{,}000} = 6{,}000$ h.p. (approx.).

A person is said to be energetic when he is capable of doing hard work, either physical or mental, and the word energy has been borrowed by science to indicate the capacity of doing the kind of work which has previously been defined.

CHAPTER III

WEIGHT, DENSITY AND EQUILIBRIUM

BECAUSE of its inertia an object does not start moving until some force acts on it, yet all things raised from the ground fall towards it if free to do so; for example, an apple drops from the tree when its stalk breaks. It is said that from wondering why this happened Sir Isaac Newton, the great eighteenth-century scientist, came to the conclusion that there is a force always acting on an object, tending to draw it towards the earth, just as if the earth and the object were joined together by an invisible elastic band. This force is called the weight of the object, or the force of gravity on the object. At first it seems strange that such a force can act without there being any material connection between the body and the earth, but actually there are other cases of forces acting between two objects not linked together materially. For example, when a rod-shaped magnet and a similar shaped iron rod are placed a short distance apart, they roll together showing that each exerts a force on the other. They are not connected yet they attract each other through space. The space may be empty of air and the magnetic attraction still takes place. The attraction between the earth and a body is called a gravitational attraction and Newton showed that this kind of attraction is not confined to the earth and the objects on it but that all pairs of bodies attract each other with forces which depend on their masses, i.e. on the number of pounds or tons of material in them, as well as on their distances apart, the force being greater the nearer they are together. This effect of gravitation explains the movements of the moon round the earth and of the earth and other planets round the sun, for the gravitational attraction supplies the necessary inward force to the centre of rotation such as is supplied by a string when a weight at the end of it is whirled round.

Density.—The mass of a particular object depends not only on its bulk or volume but also on the kind of material out of which it

is made. For example, a sack of feathers weighs less than the same sack full of lead, and some method of indicating this difference is desirable. The obvious method is to find the mass of equal volumes and to make it easier to compare various substances the mass of unit volume, such as 1 c.c. or 1 cu. ft., is usually calculated. This is known as the density and is found by dividing the mass of the substance by its volume. Thus :

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}.$$

The volume of a regularly shaped object, such as a cube or a sphere, can be calculated from its dimensions. That of an irregularly shaped object can be found by putting it in water contained in a measuring cylinder and noticing the volume of water it displaces (which is indicated by the rise of the water in the cylinder). The density of a liquid is obtained by weighing a known or measured volume of it.

It is always necessary to give the units of measurement used; for example, the density of water may be stated as follows :

Density of Water = 62·5 lb. per cu. ft.
or = 1 gm. per c.c.

It is often more convenient to use a ratio so that the units of measurement need not be stated. To do this a ratio known as the specific gravity or relative density is used. This gives the number of times the substance is heavier than an equal volume of water, thus :

$$\text{Specific Gravity} = \frac{\text{Weight of substance}}{\text{Weight of equal volume of water}}.$$

When the specific gravity is known the weight of a given volume of a substance can be calculated, as in the following examples.

Example 1 : Find the weight of a bar of iron of volume 3 cu. ft. given that the specific gravity or relative density of iron is 7·2.

Weight of 1 cu. ft. of water = 62·5 lb.
Weight of 3 cu. ft. of water = $62·5 \times 3$ lb.
Weight of 3 cu. ft. of iron = $62·5 \times 3 \times 7·2$ = 1,350 lb.

Example 2 : Find the weight of 15 c.c. of aluminium which has a relative density of 2·7.

Weight of 15 c.c. of water = 15 gm.
Weight of 15 c.c. of aluminium = $15 \times 2·7$ = 40·5 gm.

It will be noticed that the fact that 1 c.c. of water weighs 1 gram simplifies the calculation in this example.

Equilibrium.—Occasionally two teams are equally matched in a tug-of-war, and although each side is pulling with the same force in opposite directions the ribbon in the centre of the rope does not move, i.e. it is at rest. A simple experiment can be done in the laboratory to illustrate the conditions. Two spring balances can be fastened to a light object and each pulled in such a way that the object does not move. The readings of the balances are then the same and the balances have set themselves in line with each other. This shows that two forces equal in magnitude but opposite in direction balance out each other's effects in tending to make the object move. The object is then said to be in a state of equilibrium.

Under the action of two forces a body is at rest, or in equilibrium, when the two forces are equal in magnitude, opposite in direction and are acting along the same straight line.

It has been stated earlier that the force of gravity is acting on every object on or near the earth. For example, it is acting on a piece of iron which is suspended from a spring balance. But since the iron is at rest the downward pull of gravity, that is the weight of the iron, must be balanced by an upward pull on it. This upward pull is supplied by the spring of the balance which is being stretched. The spring is obviously exerting a force for when it is released, by taking off the iron bar, it flies back. If a strong spring balance is used, the return movement is small as it also is if the bar is hung from a cord which is not very elastic. Forces can act even when objects supplying them are not capable of producing any appreciable movement. All springs, cords, chains, etc., which are holding up weights act backwards with forces, and so do all objects when they resist movement in any direction. These backward forces are called reactions. Thus when an object rests on the ground it is supported by an upward force or reaction equal to the weight acting downwards on the object. An object resting on the ground presses down on it and it is this force which causes a reaction to be set up by the ground in opposition. These two forces, the first called the action and that of the ground the reaction, are equal and opposite. Whenever two objects, A and B, are in contact and A exerts a force on B, then B acts back with an equal and opposite force on A.

Tension and Compression.—When a force is exerted at one end of a rope or cord, such as when it is used for hauling or when a weight is hung from it, the force is passed along or transmitted

to the other end. Thus an engine at the top of a mine-shaft raises the cage from perhaps several thousand feet below the surface by means of a force which, exerted at the upper end of a cable, is transmitted down to the cage. The conditions when a rope or cable is used may be illustrated by means of a chain formed by stringing a number of spring balances together end to end (Fig. 24). When one end of the chain is fixed to a support and a force is exerted at the other all the balances record the same reading. At the connection of any two of them each balance acts with an equal force on the other. The measure of the force gives what is called the tension in the chain, which is the same at all points along it.

In the framework of a structure such as a bridge or roof some of the rods or girders, which are called ties, are under tension. They have forces pulling outwards at their ends. Others, called struts, have forces pushing inwards at their ends and are said to be in compression. Forces which correspond to those in a material

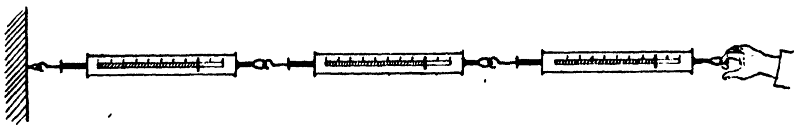


FIG. 24

under tension also act in a material under compression, such as in the legs of a table. They are forces called thrusts and tend to crush the material. Thin rods under compression also tend to buckle and then break.

Moments.—The method of obtaining balance on a see-saw is well known; the heavier boy sits nearer the support than does the lighter boy perched on the other side. Instead of a see-saw and the boys, a rod and weights can be used to study the forces concerned. The rod is pivoted at its centre and a heavy weight placed on one side. The rod is then balanced by putting a small weight at a certain place on the opposite side, the place being found by trying the weight at different points until the rod is at rest. It is found by experiment that when the weight on one side is multiplied by its distance from the pivot this product equals that of the other weight and its distance from the pivot. The product is known as the "Moment" of the force about the fixed line or axis provided by the pivot. Thus:

The Moment = Force applied × perpendicular distance from the pivot to its line of action.

For example, in Fig. 25 the moment due to the heavier weight is Wy and that due to the lighter one Fx. Since the bar is at rest

$$Wy = Fx.$$

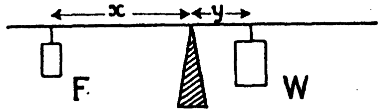


FIG. 25

Thus a boy of 8 stones (W) who is 5 feet (y) from the point of support of a see-saw will balance a boy of 6 stones (F) who is at the distance (x), calculated as follows:

$$\text{Since } Wy = Fx,\ x = \frac{Wy}{F} = \frac{8 \times 5}{6} = 6\tfrac{2}{3} \text{ feet.}$$

The Roman Steelyard (Fig. 26).—The two arms of unequal length balance each other since the shorter arm is the more massive. The object to be weighed is hung from the hook and is balanced by a small sliding weight which is moved along the longer arm until the moments about the pivot are equal. Thus it is known that the object weighs ten times as much as the sliding weight when the

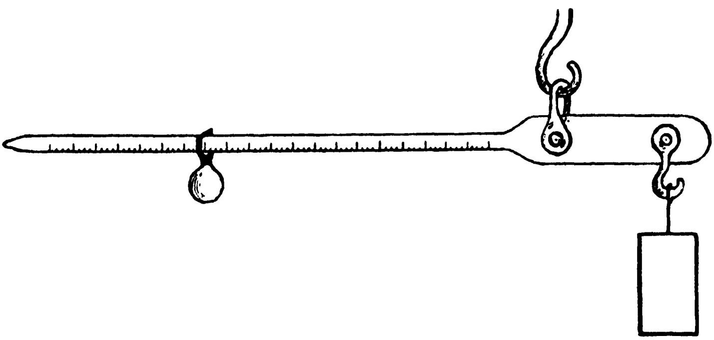


FIG. 26

slider is ten times farther from the pivot than is the hook. The long arm is calibrated to give the weight of the object directly from the position of the sliding weight.

Centre of Gravity.—The force of gravity on any object acts as if all the weight of the object were concentrated at one point. This point is that at which the body will balance in any position if supported there, and is known as the centre of gravity. A uniform rod will balance if placed with a support in the middle of it. The actual centre of the rod is the centre of gravity. A rod heavier at one end than the other balances when the support is placed at a certain point nearer the heavier end than the lighter one. By the

Principle of Moments, the sum of the moments due to the weight of each particle on the left side about any axis through the centre of gravity will be equal to the sum of the moments for the particles on the right side. An object hanging freely down from a string has its centre of gravity vertically below the point of support and in line with the string. The string may be attached to a different place on it, and the centre of gravity is again in line with the string. Thus the actual position of the centre of gravity is where the two lines intersect. For example, the centre of gravity of an irregularly shaped piece of cardboard can be found by hanging it by string first attached to one side and then another. When the cardboard is at rest, in each case a vertical line is drawn vertically downwards on it from the point of support and these lines intersect at the centre of gravity.

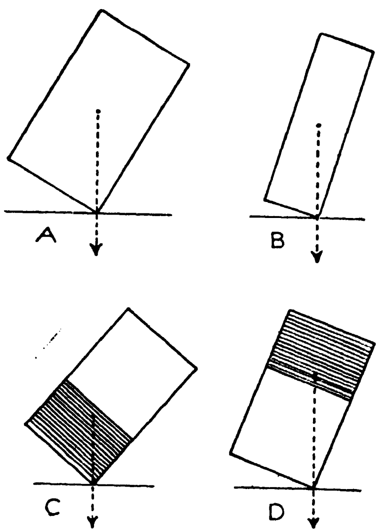


FIG. 27

The pull of gravity in effect acts vertically downwards on an object from its centre of gravity and the object will not fall over so long as a vertical line from its centre of gravity falls within its base. Thus the block of wood A (Fig. 27) will not fall on its side when tilted to a less extent than that shown but will right itself. Block B is similar to block A, but is narrower. Its centre of gravity is at the same height as that of A but its base is smaller. The extent to which it can be tilted without it falling is less than that for A. The wood block C has a heavy base and its centre of gravity is near the base whereas block D has a heavy top and its centre of gravity is high. The angle through which each can be tilted without falling over is shown in the figure. Thus an object is more stable, i.e. has less tendency to overturn, when it has a wide base and when its centre of gravity is near the base. For this reason motor-buses, which have most of their weight low down and a wide wheel-base, are stable. A table with its legs close together is more easily overturned than one the same size with its legs wider apart.

CHAPTER IV

FLOTATION

IT seems strange that an iron ship can float, for a piece of iron sinks in water. The reason for this can be approached by the simple apparatus shown in Fig. 28. This consists of a test-tube containing just enough lead-shot to make it float upright in a measuring cylinder of water. The tube with its lead-shot is weighed and then placed in the cylinder, and the difference in the two levels of the water, before and after the tube is put in, is noted. The water-level has risen since the tube has displaced some of the water and the volume displaced is found from the difference in the two readings. If this volume is given in cubic centimetres its weight can easily be calculated. It will be found that the weight of water displaced equals the weight of the tube and the lead-shot. Thus, if the tube and lead-shot weigh 80 grams, then 80 grams of water will have been displaced. When more lead-shot is added the tube sinks farther and so displaces more water. The weight of the extra volume of water equals the weight of the added shot. But unless sufficient shot is added to sink the tube the weight of the total volume of water displaced always equals the total weight of the tube plus that of the lead-shot. These facts are summarized in the Law of Flotation.

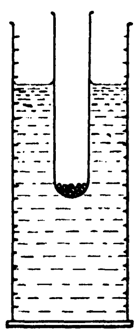


FIG. 28

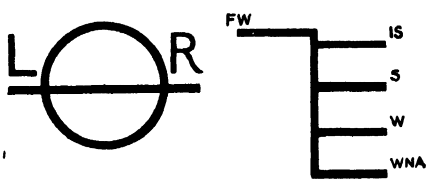
When a body floats in a liquid it displaces its own weight of the liquid.

A substance floats or sinks according to the weight of liquid it displaces when it is completely immersed. If this weight of liquid is greater than the weight of the object, the object floats, but if smaller it sinks. Consequently an object with a density less than that of the liquid floats, e.g. the relative density of cork is 0·2

and cork floats in water. But iron, with a relative density of 7, sinks.

Ships.—A floating ship can be compared with the test-tube and lead-shot. The empty ship has a very great volume relative to its weight and only a small part of it has to be immersed for the weight of water displaced to equal that of the ship. When it is loaded it sinks lower and lower, displacing more and more water, and the extra volume displaced equals the weight of the added load just as was the case in the experiment with the tube and lead-shot.

The registered displacement of a ship (which is given in tons) is the weight of the water it can displace when loaded, without fear of the vessel sinking. It is obviously an advantage to the owner of the ship to load as much cargo as possible, and this at one time led to ships often being overloaded. For many years Samuel Plimsoll tried to prevent this, and was successful in 1876, when an Act was passed by Parliament making it illegal to overload. On the hull of every ship a line must be marked to indicate the depth to which the ship can safely float in the water when loaded. This line is called the Plimsoll Line (Fig. 29) and its position is fixed by agents of Lloyd's Register who paint their mark upon the side. The density of water varies according to whether it is fresh or salt water, and also according to the temperature. The volume of it displaced therefore varies, the denser the water the smaller is the volume of it which the ship displaces. Five levels are marked on the ship's side. These are indicated in the figure and the ship must be loaded so that the water does not reach higher than the mark corresponding to the kind of water in which it is floating (see note to the figure).



L.R. *Lloyds Register* S. *Summer in Temperate latitudes*
F.W. *Fresh Water*
I.S. *Indian Summer* W. *Winter*
W.N.A. *Winter in North Atlantic*

FIG. 29

A submarine floats on the surface of the water for the reasons given before. It is gradually submerged by pumping water into tanks, thereby increasing the total weight. When completely submerged it is displacing its own volume of water, which weighs

the same as the submarine, and it can move about under the water at any depth. To bring it back to the surface compressed air is forced into the water-tanks. The water then contained is forced out and the weight of the submarine obviously becomes smaller and so the vessel rises to the top. An airship floats in the air when the volume of air it displaces weighs the same as the airship. The airship, as will be mentioned later (page 65), is filled with a light gas such as hydrogen or helium, so that although it has a large volume and contains some heavier material than air its total weight is the same as the volume of air it displaces.

The Floating Dock.—Ships needing repairs sometimes have to be taken completely out of the water. This may be done by sailing the ship into a "floating dock," which is open at the two ends and sunk so that the ship can sail over the bottom. The sides and bottom are hollow and when sunk are full of water. When the ship is in position the water is pumped out and air takes its place. The weight of the floating dock becomes considerably reduced and, despite the great weight of the ship which is resting on it, the dock rises, carrying the ship with it.

Hydrometers.—In one method of finding the specific gravity of a liquid an instrument called a hydrometer, Fig. 30, is used. This is shaped as shown and also loaded at the bottom so that it floats upright. The stem is graduated so that when the hydrometer is placed in water the level of the water reaches the mark 1·0 on the stem. When placed in a liquid which is denser than water it does not sink as far since a smaller volume of the denser liquid weighs the same as the hydrometer. The scale is graduated so that direct reading of the level indicates the specific gravity of the liquid. Hydrometers are used for testing the composition of liquids; for example, the specific gravity of milk can be readily found by floating one in the milk and noticing the mark to which it sinks. If water has been added to milk this can be detected, for the specific gravity is less than that of unadulterated milk. The specific gravities of alcoholic beverages, oils and sulphuric acid for the accumulator are also found by use of the hydrometer.

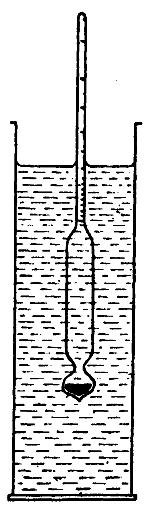


FIG. 30

Archimedes' Principle.—Water has a buoyant effect, as every swimmer knows. A common practice when teaching a person to

swim is for the instructor to place a hand under the swimmer and support him. The instructor certainly could not lift the person in air by exerting the small force he has to exert in the water. Many boys know how easy it is to lift a heavy stone under water, and those who have tried it are usually surprised at the apparently great increase in weight of the stone immediately it reaches the surface. This buoyant effect is due to an upward force which in the case of a body which is floating balances the downward force of gravity. The upward thrust is not, however, sufficient to support an object denser than the liquid, though it acts as a partial support. The effect can be studied by using the apparatus shown in Fig. 31. A small stone is weighed by suspending it from the spring balance. It is then lowered completely into the water and the reading on the balance shows a much smaller reading. This *apparent* loss in weight of the stone is recorded. The stone is then put in a measuring cylinder of water, the level of the water rises and the rise gives the volume of the stone. It is always found that the weight of the water displaced equals the apparent loss in weight of the stone. That is, the apparent loss in weight equals the weight of water which has the same volume as the solid. This fact was discovered by an early Greek philosopher, Archimedes, and is embodied in the "Principle of Archimedes":

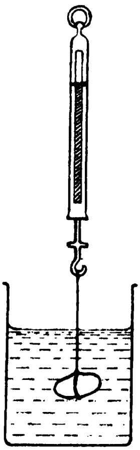


FIG. 31

When a body is completely immersed in water (or other liquid) its apparent loss in weight equals the weight of the water (or other liquid) it displaces.

(The apparent loss in weight is due to the upthrust of the water.)

It follows from this principle, since

$$\text{Specific Gravity} = \frac{\text{Weight of solid}}{\text{Weight of an equal volume of water}},$$

that

$$\text{Specific Gravity} = \frac{\text{Weight of solid}}{\text{Apparent loss of weight in water}}.$$

Archimedes' Principle gives a method of finding the specific

gravity of a solid. For example, if a brick which weighs 7 lb. apparently only weighs 4 lb. when completely immersed in water, its apparent loss is 3 lb.

$$\therefore \text{ Specific Gravity} = \frac{\text{Weight of Brick}}{\text{Apparent loss in weight}} = \frac{7}{3} = 2\cdot 3.$$

CHAPTER V

SIMPLE MACHINES

A CROWBAR is one of the simplest of machines and by its use a heavy weight, such as a rock, can be lifted by using much less force than would be necessary without it. All machines resemble the crowbar in that they are contrivances which assist in doing work. Many of them, such as sewing-machines and typewriters, are quite complicated and may produce a number of different movements at the same time. They are usually found, however, to consist of parts which are themselves simple machines, such as geared wheels and pivoted rods which act as levers.

A crowbar is a form of lever. Often a small stone is placed below the bar a few inches from the end which is pushed beneath the object which has to be lifted. The bar is forced downwards at the other end and turns about the stone, which acts as a pivot or fulcrum. In so doing it exerts an upward force on the object and raises it. This upward force is equal to the weight of the object which is acting downward and opposing it. There are certain terms commonly used in describing levers. The weight lifted is known as the load and the force exerted on the lever the effort; the part of the bar from the fulcrum to the effort is called the effort arm and that to the load, the load arm. The relation between the load and the effort is found from the principle of moments, for they act as balanced forces tending to turn the bar in opposite directions about the fulcrum. Suppose that the load arm of the crowbar is 4 inches, the effort arm 36 inches and the load 90 lb., then the effort, F, is calculated, using the principle of moments, as follows:

$$\text{Effort (F)} \times \text{Effort Arm} = \text{Load (W)} \times \text{Load arm.}$$

$$\text{Effort (F)} = \frac{\text{Load} \times \text{Load Arm}}{\text{Effort Arm}} = \frac{90 \times 4}{36} = 10 \text{ lb.}$$

The advantage of using a crowbar can be measured by dividing

the load raised (90 lb.) by the effort needed to raise it (10 lb.). This ratio is generally known as the mechanical advantage and in this example equals 9.

$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}} = \frac{90 \text{ lb.}}{10 \text{ lb.}} = 9.$$

The same value is obtained when the length of the effort arm is divided by that of the load arm, thus in this example:

$$\frac{\text{Effort Arm}}{\text{Load Arm}} = \frac{36 \text{ in.}}{4 \text{ in.}} = 9.$$

Hence:

$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}} = \frac{\text{Effort Arm}}{\text{Load Arm}}.$$

This ratio also gives the distance the load will be moved for a definite distance moved by the effort. Thus:

$$\frac{\text{Effort Arm}}{\text{Load Arm}} = \frac{\text{Distance moved by Effort}}{\text{Distance moved by Load}}.$$

In this example the ratio equals 9. When the effort moves through 1 ft. the distance moved by the load is $\frac{1}{9}$ ft.

The work done in producing the movement is the effort multiplied by the distance through which it moves.

In this example it is $10 \times 1 = 10$ ft. lb.
The work needed to raise the load is $90 \times \frac{1}{9} = 10$ ft. lb.

Thus the work put into the machine is equal to the work got out. A crowbar, or any machine, enables the work to be done more conveniently but it does not lessen the amount to be done. If there is a gain in force needed to do the work it is offset by a greater movement being necessary and so a slower rate of movement.

Classes of Levers.—Many simple tools and appliances used in daily life are levers. In some, two levers act together, forming a double lever. Each blade of a pair of scissors with the handle attached to it is a lever. The turning-point is the rivet; the effort is applied at the handle while the "load" is provided by the material, which offers a resistance to being cut. This is shown diagrammatically in Fig. 32. It has been found convenient to group all levers into three classes according to the relative position of the load (W), the fulcrum and the effort (F).

Class I levers. The fulcrum is between the load and the

effort, e.g. the crowbar, a tack-lifter, a pump-handle, the pair of scissors.

Class II levers. The load is between the fulcrum and the effort. The wheelbarrow (Fig. 32) is a common example ; the wheel is the fulcrum, and the weight in the barrow is the load. The effort, obviously, is applied at the handles. Other examples are, a crowbar (when the ground is used as the fulcrum and the weight to be lifted rests some inches from the end of the bar), and a pair of nutcrackers, each prong of which is a lever.

Class III levers. The effort is between the load and the fulcrum. the human forearm (page 325), is pivoted at the elbow, which is the

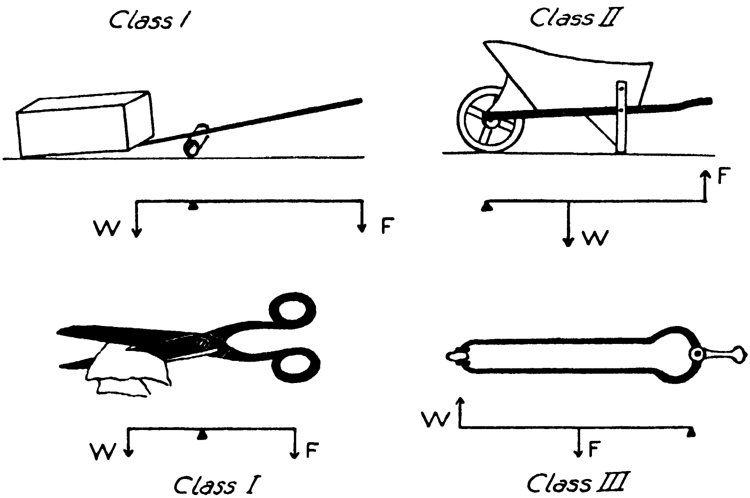


FIG. 32

fulcrum. The load to be lifted is in the hand and the muscles exerting the effort act between the elbow and the hand. Indeed the forearm is a good example of the bones of the body acting as levers. By their use a small movement of the muscle produces a wide range of movement of the limb and of the load moved, and this also makes for added speed of action. The muscle, however, has to exert a large force to raise a small object, i.e. there is a mechanical disadvantage, since the effort is greater than the load. Thus if a load of 20 lb. is raised in the hand the muscles, mainly the biceps, have to exert a force of about 200 lb, since the muscles pull at a distance from the joint about one-tenth of that from the joint to the hand.

All Class III levers give a mechanical disadvantage. Fire-tongs (Fig. 32) and sugar-tongs are double levers of this type, as is indicated in the diagram. The oar of a rowing-boat is a Class I lever designed so that the rower pulls hard on his end, moving it but a short distance compared with the distance the blade of the oar moves in the water. Actually the rower is exerting more force than the oar-blade exerts on the water, i.e. there is a mechanical disadvantage, since the effort is greater than the load. The reason is obvious in this example because the distance moved by the load arm is of importance. Class II levers must always give a mechanical advantage, since the load arm is part of the effort arm.

Simple Pulley.—A rope by itself can only be used to give movement in one direction. To enable movements to be made in directions other than that in which the force or effort is applied, a simple fixed pulley may be used in the manner shown in Fig. 33. If the pulley is perfectly free to move about its axle the pull or tension in the string is the same on both sides of the pulley so that the effort is equal to the load. The free end may be pulled in any direction provided the string still remains partly in the groove round the pulley, the effort needed remaining the same.

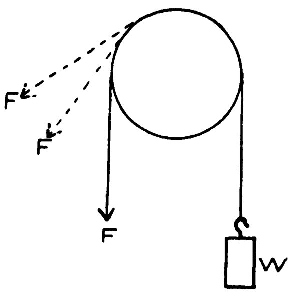


FIG. 33

A simple pulley is frequently used for raising weights. There are two main advantages, the first being that a downward pull is usually easier to exert than an upward pull and the second that the force can be exerted from below the object lifted. The force needed to produce the movement is not reduced by using the pulley, indeed it is slightly larger in practice than the weight lifted, for there is usually some resistance to turning in the pulley. In order to obtain the movement by exerting an effort smaller than the load one or more moving pulleys must be used. Two pulley-blocks are used, each containing a number of sheaves or individual pulleys. Fig. 34 shows such a system of pulleys, A, and by its side is given the usual diagrammatic way, B, of representing it. The moving block (the lower one), to which the load is attached, is connected to a similar fixed block (at the top) by a cord which has one end fastened to one of the blocks and then passes a number of times from one block to the other round the sheaves. It finally passes

over the fixed block so that the applied force or effort may be exerted on the free end. If there is no friction in the various pulleys the tension in the cord passing round them is the same throughout and equal to the force exerted on its free end. The load that might possibly be raised can be seen from the equilibrium of the lower pulley. It is supported by a number of vertical parts of the cord. For example, if there are six of these, as in Fig. 34, the load is supported by six times the tension, or six times the applied force. So that it should be possible to raise a load by an effort or applied force of one-sixth of the load and so obtain a mechanical advantage (load ÷ effort) of six. In practice this advantage is reduced by friction and by the weights of the blocks and cords. The advantage gained in this way is offset by the disadvantage that the free end of the cord must be pulled through a greater distance than that moved through by the load. Taking the same example as before, when the load is lifted one foot the length of each of the six parts of the cord connecting the blocks is reduced by this distance. The free end must therefore be pulled through 6 feet. The distance the end of the rope is moved divided by the distance moved by the load is known as the velocity ratio. Hence:

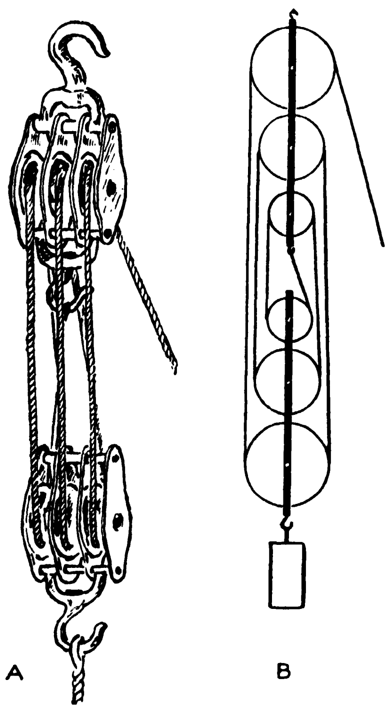


FIG. 34

$$\text{Velocity ratio} = \frac{\text{distance moved through by effort}}{\text{distance moved through by load}}.$$

In the above example the velocity ratio is 6 and it is equal to the mechanical advantage assuming that the machine is without friction and without weight. In practice the mechanical advantage is less than the velocity ratio, and the pulley system is less efficient than is a perfect machine. The efficiency of a machine is calculated as follows. Suppose an effort F is required to raise a load W and

that the distance moved through by the effort is x feet and that by the load y feet. Then

$$\text{Work put into the machine} = Fx \text{ ft. lb.}$$
$$\text{Work got out of the machine} = Wy \text{ ft. lb.}$$

$$\text{Efficiency of machine} = \frac{\text{work got out}}{\text{work put in}}$$
$$= \frac{Wy}{Fx} = \frac{W}{F} \div \frac{x}{y}.$$

But $\frac{W}{F}$ = Mechanical Advantage and $\frac{x}{y}$ = Velocity Ratio.

$$\therefore \text{Efficiency} = \frac{\text{Mechanical Advantage}}{\text{Velocity Ratio}}.$$

Thus if it is found by trial that a six-stringed pulley system (as described) will raise a load of 90 lb. when an effort of 18 lb. is exerted, then

$$MA = \tfrac{90}{18} = 5.$$

The velocity ratio is 6.

$$\therefore \text{Efficiency} = \tfrac{5}{6} \text{ or } 83\tfrac{1}{3} \text{ per cent.}$$

Differential Pulley.—This is illustrated in Fig. 35 together with a diagrammatic sketch. It will be seen that there are two pulleys of different diameters in the upper block, which are fixed together. An endless chain passes round these and round the lower movable pulley to which the load is attached. The chain cannot slip since its links engage in recesses in the pulley rims. An example will show the velocity ratio of the machine. Thus if the larger upper pulley has a circumference of 30 inches and the smaller one a circumference of 28 inches, in a single turn of the block the effort moves through 30 inches. The part of the chain from which the load hangs winds up around the larger pulley 30 inches of chain

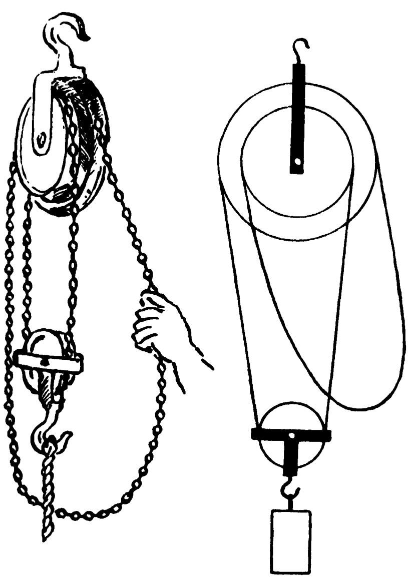


FIG. 35

on one side while it unwinds 28 inches off the smaller pulley. Thus the loop round the lower pulley is reduced in length by two inches and the load rises one inch, giving a velocity ratio of 30. The mechanical advantage is much less than this owing to friction.

The Wheel and Axle.—Fig. 36 shows a common windlass or wheel and axle such as is used for raising water from a well. The moment of the load W about the axle is WR, where R is the radius of the axle or drum round which the rope winds. The moment of

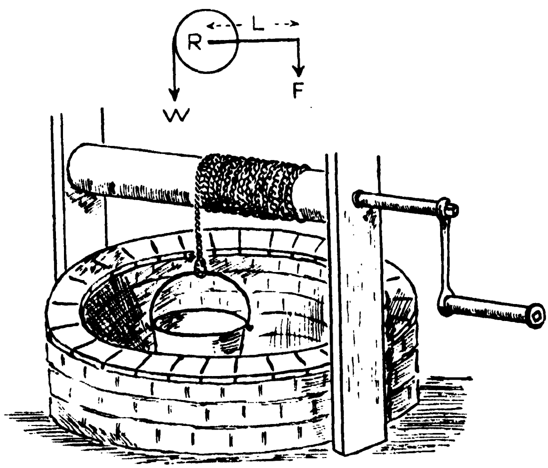


FIG. 36

the effort equals FL, where L is the radius of the circle through which the handle moves and is greater than the radius of the drum.

Hence FL = WR

and the mechanical advantage (when frictionless)

$$\frac{W}{F} = \frac{L}{R}.$$

Hence the velocity ratio $= \dfrac{L}{R}.$

There are several modifications of the wheel and axle, such as the capstan.

CHAPTER VI

PRESSURE

WATER comes out of the tap with considerable force when it is turned on. Rivers and streams never run up-hill, yet water in pipes can be led up streets and hills and from the underground mains to the top of a high building. The conditions inside a full water-pipe are evidently different from those in an open stream or river. The pipes are connected either to a reservoir, which is situated at a much higher level than the town, or else to a tank at the top of a high water-tower, the tank being full of water which has been pumped up into it (page 216). Thus the water flows through the pipes from a much higher level, and it is because of this that it can be led up and down the streets of the town and that it comes out of the tap with considerable force. This force can be demonstrated by using a large inverted bell jar, Fig. 37, as the reservoir and a piece of glass tubing as the water-pipe. The water rushes out of the tube with considerable force, the force increasing the lower the jet is below the surface of the water in the jar. Water and all liquids have a tendency "to find their own level" and but for resistances to the passage of the water the fountain would rise to the height of the level of the water in the jar.

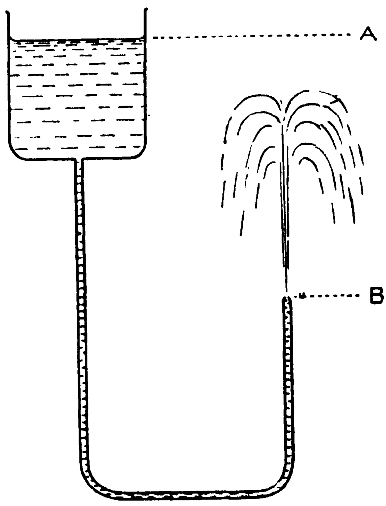


FIG. 37

This tendency can be shown by filling the apparatus, Fig. 38, with water. Each tube is open at the top and the level of the

water becomes the same in each. Use is made of this property in many appliances, e.g. the water-gauge of the boiler (Fig. 39).

When water is poured into the jar, Fig. 40, it flows out of the holes, as indicated, coming out fastest at the bottom hole.

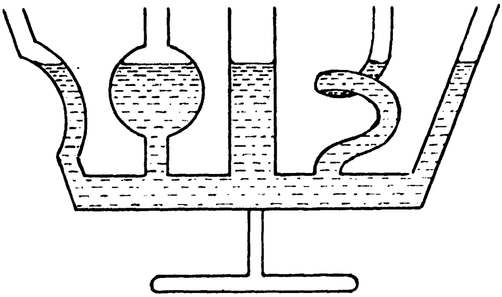


FIG. 38

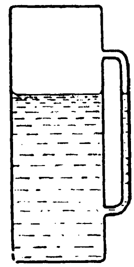


FIG. 39

Obviously water is pressing against the side of the jar or else it would not flow out, and the pressure is greatest at the bottom.

The pressure at any height of water can be calculated, knowing that 1 cubic foot of water weighs 62½ lb. A column of water one foot high exerts a downwards force of 62½ lb. on a surface of an area of one square foot, while a two-foot-high column on a similar surface has a pressure of 125 lb. and so on. It will be seen that the pressure at the foot of a column of water varies directly with the vertical height of the column. The pressure exerted by a liquid is the same in all directions. This is shown by the way water squirts out of a burst pipe no matter on what part of the surface of the pipe the hole is. The calculation of the downward pressure gives the value of the pressure in all directions. The pressure is frequently expressed in pounds per square inch. Some idea of the pressure at great depths in water can be got, since the pressure below the surface of the water increases for each 100 feet of depth by

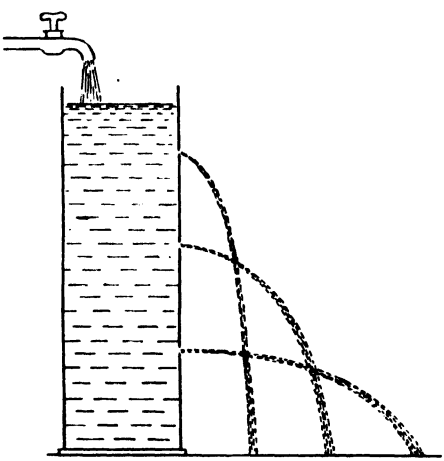
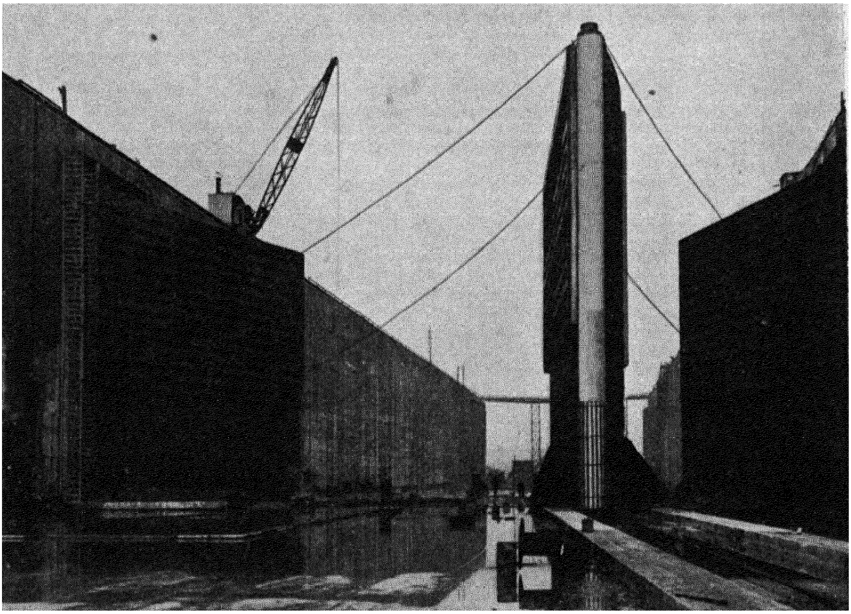


FIG. 40

$62{\cdot}5 \times 100$ lb., on each square foot or $\frac{62{\cdot}5 \times 100}{144} = 56$ lb. on each square inch. The pressure exerted in all directions on a diver's suit is, therefore, 56 lb. on each square inch of the suit for each 100 feet the diver is below the surface. The greatest depths of the ocean have never been explored because of the high pressure reached, though observations have been made from a large steel ball let down to a depth of about 6,000 feet. The larger the size of such a ball



Courtesy of Mersey Docks and Harbour Board

FIG. 41

Gladstone Dock, Liverpool: Lock Gate being Moved into Position

the greater is the tendency for it to collapse inward because the total force or thrust on a surface depends on its area as well as on the pressure. This total force or thrust of a liquid on a surface is found from the product of the pressure and the area against which it is pressing, thus Thrust = Pressure × Area. The dam walls of a reservoir, as well as sea walls, have to withstand a very large thrust. They are built with the walls thicker and stronger at the bottom than at the top for the thrust to be opposed is so much

greater at the bottom. Lock gates also have to withstand great pressures. The photograph, Fig. 41, shows a new gate, 65 feet in width, being moved into position during the building of a large dock on the Mersey. High-water mark is about 48 feet, so that the height of the water pressing against the gate at high tide will also be 48 feet. The area against which the water will press equals 65 × 48 square feet. The centre of the water will be 24 feet below the surface and so the average pressure on each square foot will be 24 × 62·5 lb. Hence the total thrust on the lock gates will be 65 × 48 × 24 × 62·5 lb. = 2,200 tons (approx.). (Actually, sea water is heavier than fresh water and 1 cu. ft. weighs more than 62·5 lb.)

Head of Water.—In a water-pipe the pressure depends on the difference in level between the water in the pipe and that in the reservoir supplying it. This difference in level is called "the head of water," e.g. the head at B in Fig 37 is the height AB. When the head is 100 feet the pressure in a pipe is 56 lb./sq. in., just as it would be at the same depth below the surface of an expanse of water. The pressure is the same at all parts of the system of pipes which are at the same horizontal level.

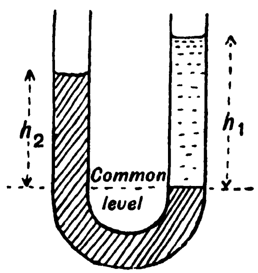


FIG. 42

It has been mentioned that the pressure at the bottom of a column of water 2 feet high is 62·5 × 2 lb. and in general the pressure at any point in water is $h \times 62{\cdot}5$ lb. per square foot where the "head" is h feet. When the head is h cm. the pressure is h grams per square centimetre. The pressure in any liquid is therefore $h \times 62{\cdot}4 \times d$ lb. per square foot where d is the specific gravity of the liquid, or $h \times d$ grams per square centimetre.

The effect of specific gravity on the pressure may be illustrated by balancing two liquids which do not mix, such as oil and water, in the **U**-tube (Fig. 42). The pressure in the left-hand limb at the common level is h_2d_2 and in the other limb h_1d_1. These two values are equal, i.e. $h_1d_1 = h_2d_2$. Thus the ratio of the two densities is :

$$\frac{d_1}{d_2} = \frac{h_2}{h_1}$$

and if the density of one liquid (e.g. water) is known, that of the other liquid can be found.

A Hydraulic Press.—A simple form of the press is shown in Fig. 43. Suppose the area of the narrow column is 1 square inch and that of the other 10 square inches. A weight (say of 2 lb.) placed on A will then exert a pressure of 2 lb. on each square inch. This pressure is transmitted equally through the water in all directions and hence the upward pressure in the wider column is 2 lb. per square inch. Since the area of the surface of the water is 10 square inches the total upward pressure on the piston supporting D is 20 lb. Hence the 2 lb. weight at A will support a 20 lb. weight at D. This principle of using water to multiply forces is made use of in hydraulic presses or jacks, though liquids such as oils are frequently used in place of water.

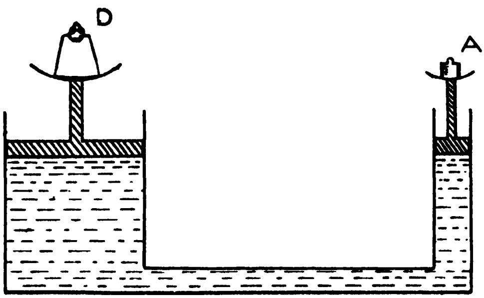


FIG. 43

AIR PRESSURE

Although we live at the bottom of an ocean of air we are not usually conscious of its presence, for it cannot be seen, smelled or tasted. But when the wind blows strongly we realize that something is present. Winds are masses of moving air and the air then behaves like other substances in motion ; it exerts forces which can set things in motion and which are sometimes strong enough to push down trees and buildings. Indeed, air is a material substance and occupies space as water and other substances do. This fact becomes evident when an "empty" bottle is inverted vertically in a trough of water and tilted sideways. Bubbles of air escape from the bottle and the water enters to take the place formerly occupied by the air.

Air, like other substances, has weight. This can be shown by pumping the air out of a vessel, such as a large sphere ; the exhausted vessel is then weighed and the air is allowed to enter it. It is then re-weighed and an increase in weight is found.

Although air is very light, a cubic foot of it weighing little more than an ounce, there is such a large height of it pressing on the earth that the pressure it produces is considerable, being about

15 lb. per square inch of the surface. This pressure is not acting merely in a downwards direction but, like the pressure in a liquid, is exerted on all surfaces in contact with it. The following experiment illustrates this fact. A large empty tin is filled with water to a depth of a few inches. The water is boiled and the steam drives out most of the air. The cap is screwed on and the steam inside is then condensed by pouring cold water over the can. Since there is then little air in the space above the water the can crumples up as shown in Fig. 44. The can has not only been " concertina-ed " downwards but has collapsed on every side. The pressure of the air on the outer surface must have been considerable to produce the effect shown. It might be wondered how the sides of the can normally withstand this pressure. The can does not collapse when full of air, for the air inside is pressing outwards with the same force as the outer air is pressing inwards and there is, therefore, no resultant force (just as there is none when two boys are pushing with equal force on opposite sides of a swing door, for the door remains stationary).

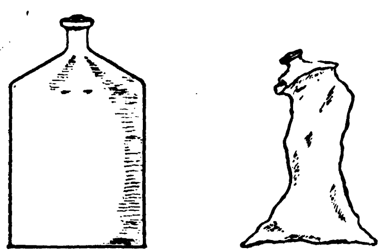
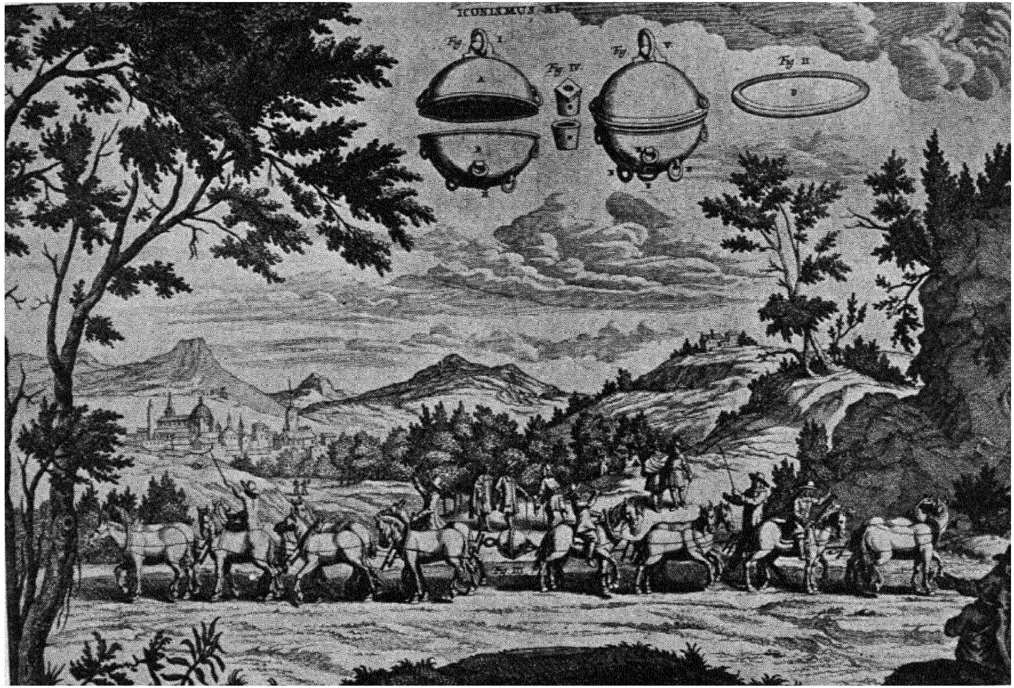


FIG. 44

Another example illustrating air pressure is a well known " conjuring " trick. A tumbler is filled brimful with water and a thin piece of cardboard is put on top. The cardboard is held in position by the hand while the tumbler is turned upside down and then the hand is removed. The cardboard remains apparently stuck fast despite the weight of the water which is pushing down on it. There must obviously be a force pushing upwards and this force is due to the upward pressure of the air, which is more than sufficient to hold up the weight of the water in the tumbler. It is the pressure of air which makes a sucker stick against a smooth surface. The rubber or leather disc is pressed against the surface and the air is thus forced out from underneath it. Hence the air is pressing only against its outer surface and so makes the sucker stick.

One of the most famous experiments showing the force exerted by the pressure of the air was made, about 1650, by the Burgomaster of Magdeburg, a German named Von Guericke (see illustration, Fig. 45). He fitted together two large hemispheres of about four feet in diameter, so forming a hollow sphere. The air was then



Courtesy of Messrs. George Bell & Sons, Ltd.

FIG. 45

Guericke's Magdeburg Hemispheres

(From Nightingale's Experimental Hydrostatics and Mechanics)

pumped out of this hollow sphere by an air-pump which he had devised and made. Hence the air was pressing on the outer surface of the sphere only. So great was the force exerted on this surface that it took two teams each of eight horses to drag the hemispheres apart.

Effect of Air Pressure on the Surface of Water.—When we "suck up" lemonade, etc., through a straw, what really happens is that some of the air is withdrawn from the tube above the surface of the lemonade, thus decreasing the pressure of the air inside the tube. The pressure of the air outside the tube is then greater than that inside and this greater pressure, which acts on the surface of the lemonade in the glass and then through the liquid, forces the lemonade up the tube. A pipette is filled in a similar manner. In a fountain-pen filler the squeezing of the bulb forces some of the air out of the inside of the tube and the ink rises for the same reason.

Measurement of Air Pressure.—This is done by using an instrument called a barometer, the simplest kind of which consists of a tube about 33 inches long sealed at one end. This tube is filled with mercury (quicksilver) and inverted vertically in a basin containing mercury. (The thumb is placed over the open end while inverting the tube.) The mercury-level then falls until it is about 30 inches higher than the surface of the mercury in the basin and an empty space, or vacuum, is left at the top of the tube. It does not matter how wide the tube is or whether it is slanting so long as there is a vacuum above the mercury; the vertical height of the column is always the same (see Fig. 46). The pressure of the air is exerted on the surface of the mercury in the basin and there must be the same pressure at the same level in the tube. This air pressure is balanced by the weight of the column of mercury, for there is

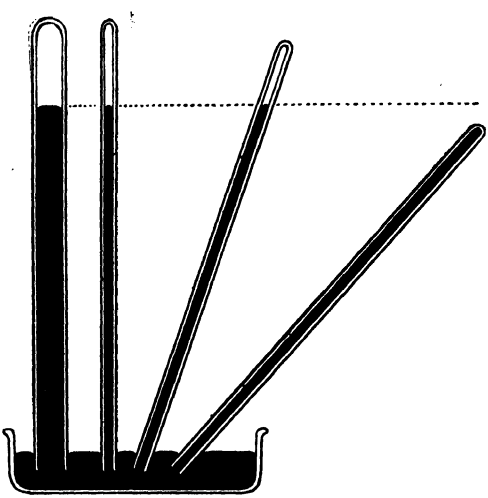


FIG. 46

no air to press down above the mercury in the tube. It is customary to express the pressure of the air as being so many inches of mercury, indicating the height of a column of mercury it can support.

The relative density of mercury is 13·6 and 1 cubic foot of water weighs 62·5 lb., therefore 1 cubic foot of mercury weighs $13{\cdot}6 \times 62{\cdot}5$ lb. Hence the pressure of a column 30 inches high, i.e. $2\frac{1}{2}$ feet, on each square foot will be $13{\cdot}6 \times 62{\cdot}5 \times 2\frac{1}{2}$ lb. and on one square inch

$$\frac{13{\cdot}6 \times 62{\cdot}5 \times 2{\cdot}5}{144} \text{ lb.} = 14{\cdot}6 \text{ lb.}$$

When the atmospheric pressure equals 30 inches of mercury it follows that the atmospheric pressure is 14·6 lb. per square inch.

In the old type of "weather glass" the tube is shaped like a letter J, the longer limb being about 36 inches high and sealed at the top (Fig. 47). The atmospheric pressure is equal to the difference in heights of the two mercury-levels, but since it would be inconvenient to have to measure this difference repeatedly a mechanical device is used. A small weight floats on the open surface and is balanced by another weight as shown. Any change in level is indicated by a movement of the pointer over the face of the weather glass which is calibrated in inches of mercury. This type is now largely replaced by the aneroid barometer, which contains no mercury at all and works on a different principle.

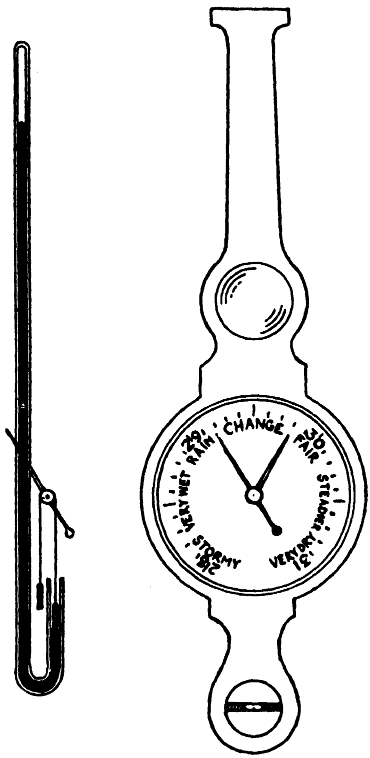


FIG. 47

The Aneroid Barometer.—The effect of exhausting the air from a tin vessel was mentioned on page 42 and use is made of this in the aneroid barometer. Its essential part is an air-tight cylindrical box out of which the air has been pumped (Fig. 48). The top of the box is made of thin corrugated steel and would collapse (just

as the tin can did, Fig. 44) but for a curved spring which supports it. Changes in the air pressure increase or decrease the force on the top of the box. The spring moves down or up accordingly, but since the movement is a slight one it is magnified by a system

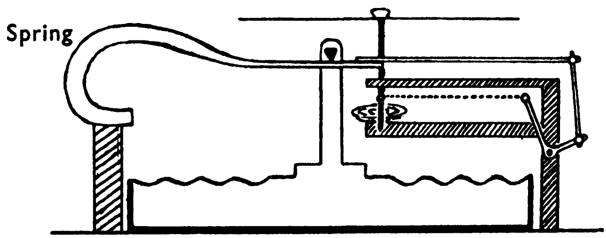


FIG. 48

of levers as shown in the figure. The movement is passed by a chain to the pointer which turns over the face of the instrument. The face is calibrated in inches of mercury.

The Altimeter.—Just as the pressure of a column of water increases with the depth of the water so also does the pressure of the atmosphere vary with the altitude, i.e. height above sea-level. Thus, on a mountain-top the height of air is less than it is at sea-level and so the pressure of air is correspondingly less. At low altitudes the pressure decreases 1 inch of mercury for about every 900 feet rise in altitude. Thus a barometer can be used to find the height of a mountain and an aneroid barometer is obviously a more convenient one to use for this purpose than a mercury one. Instead of marking the face in inches of mercury it is marked in feet above sea-level. Such an instrument is known as an altimeter and is fitted to aeroplanes, etc., and carried by mountaineers.

It has been estimated that the pressure of the air 10 miles above the ground is about one-third of that at sea-level. The air is evidently very sparse in this upper region which is called the stratosphere. The air tends to fill equally all the space available for it but there is the opposing action of gravity on it which tends to keep it near the earth.

The Barometer and Weather Changes.—Variations of the air pressure give some indication of weather changes, e.g. a fall in the barometer is often an indication of approaching bad weather. But reliable forecasts can only be made from barometer readings taken over a wide area. For example, the weather forecasts of this

country are based on barometric readings taken in different parts of Europe and on the high seas.

The Cycle Pump.—The action of most pumps depends on the pressure of the air. The piston in a cycle pump is fitted with a cup-

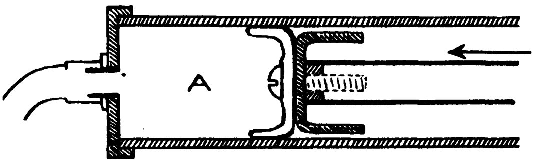


FIG. 49

shaped leather washer which points towards the outlet, Fig. 49. When the handle is pulled out the flexible washer is not in close contact with the walls of the tube and air enters the space at A. As the rod is pushed inwards the air in the barrel becomes compressed and presses against the washer with a greater force than the outside air is exerting in the opposite direction. The washer is therefore pressed tightly against the wall as shown in the figure and no air can escape round it. When sufficient pressure is reached in A the air is forced through the valve into the tyre.

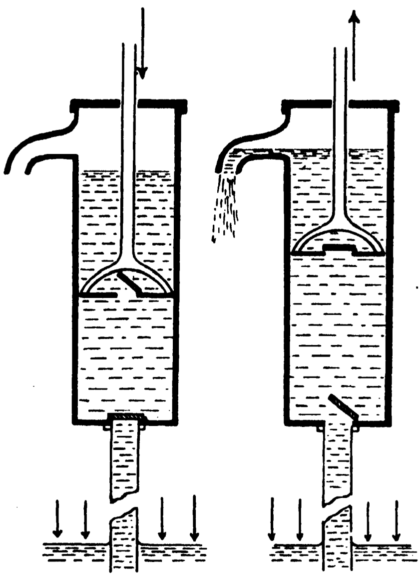


FIG. 50

The Common Pump which has been known for centuries is illustrated in Fig. 50. The tightly fitting piston is moved up and down the barrel of the pump by working the handle. There are two valves, one in the piston and the other at the bottom of the barrel and each of them can move upwards only. Suppose the water is below the bottom of the barrel to start with. As the piston rises the pressure of the air in the space below it is reduced, since that present is given more space. Hence the pressure is less than atmospheric, and the air, pressing on the surface of the water in the well at

a greater pressure than that inside the pipe, forces the water up the pipe. The piston is then moved downwards, so increasing the pressure in the space below it. This increase in pressure causes the lower valve to close but forces the piston valve open, since the pressure above it is now less than that below it. This allows the piston to move downwards. On each upstroke the lower valve opens and the piston valve closes and the water in time becomes level with the spout and flows out. It has been mentioned that air supports a column of mercury 30 inches high. Mercury has a density of 13·6 and hence air can support a column of water of a height of $30 \times 13{\cdot}6$ inches $= 34$ feet. Theoretically, therefore, the common pump should act with the piston working to that height, but pumps differ greatly in efficiency and in the majority the maximum height is little over 20 feet or so.

The Force Pump.—This is used for raising water to a considerable height or for driving it at a pressure through pipes. It has

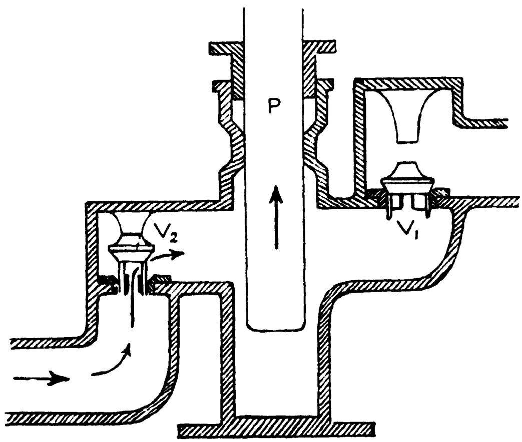


FIG. 51

no valves in the piston which is often replaced by a plunger P as shown in Fig. 51. There is an outlet pipe leading from the barrel and at the entrance to the pipe is a valve V_1 opening outwards from the pump. The water is raised into the barrel through a valve V_2 the action being the same as in the common pump. As the plunger moves downwards the water in the barrel is forced through the valve in the outlet pipe and along the pipe to any required height. In the upstroke the valve V_2 is opened and more water enters the

barrel while V_1 closes, so preventing the liquid from passing back into the pump.

The Syphon.—This is another device which depends on air pressure. It consists simply of a bent tube with one limb longer than the other, Fig. 52, and is used for emptying vessels without having to tilt them. The shorter limb is dipped in the liquid and when the whole tube is filled the liquid then flows out of the longer limb. The reason for this is that the pressure due to the head of liquid in the right limb of the tube, which tends to cause the flow, is greater than the corresponding head in the left limb which opposes it. That in the right limb is from C, the highest point in the tube, to D, the open end, while that in the left limb is from C to the level of the liquid at A. B is a point level with the liquid surface. Consequently it is the pressure equivalent to the head of liquid from B to D which provides the force which sends the liquid through the pipe, and the lower the open end is below the level of the liquid in the tank the more rapid is the flow. The action also depends on the air pressure which is necessary to support the liquid above the level AB.

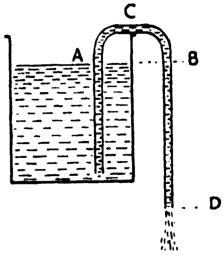


FIG. 52

CHAPTER VII

AIR

A VERY noticeable change takes place when many of the metals are heated in the air, particularly when they are strongly heated. For example, when the plumber heats lead in a pan a "scum" forms on top of the molten lead; when the blacksmith heats iron to white-hotness and then hammers it on the anvil, small white-hot flakes fly in all directions. When one of these flakes is cold, the original colour of it has changed and is then blue. A few simple experiments in the laboratory show how some of the metals change. Thus, a thin piece of lead, or copper, or magnesium can be strongly heated on a crucible lid. The lead leaves a yellowish ash or powder, the copper is turned black and the magnesium bursts into flames, leaving a white ash or powder on the crucible lid. But when gold is heated in this way it does not change into another substance.

The Alchemists.—This effect of heat on metals was known to the alchemists, who were the forerunners of the modern scientists. They classified the metals into two classes:

(*a*) Base Metals—metals which change into ashes on heating in air, e.g. lead, tin, copper, iron.
(*b*) Noble Metals—metals which do not change on heating in air, e.g. gold, silver (and platinum).

Mankind has always desired wealth and many of the alchemists tried to discover a substance which, when added to a base metal, would change it into gold. Although such a substance was never discovered it became known as the "philosopher's stone." Besides wealth mankind has always wanted good health and certain alchemists tried to discover a wonderful medicine which would give perfect health and long life to all who partook of it. This, the "elixir of life," was also not discovered.

These alchemists often worked in secret and in what seem to

Courtesy of Rischgitz Art Studios

FIG. 53

An Alchemist in his Laboratory

(After Teniers)

us to be very primitive laboratories. A reproduction of a famous painting of such a laboratory is seen in Fig. 53.

Air and Burning.—By the middle of the seventeenth century some approach to modern scientific methods were being made. For example, in the reign of Charles II, Robert Boyle invented the air pump by means of which air could be pumped out of a vessel. In one experiment he placed a red-hot piece of charcoal in a vessel and pumped out the air. The charcoal gradually ceased to glow and in time stopped burning. He then allowed the air to enter the vessel and the charcoal glowed again. This showed him that charcoal burns in air but not in the absence of it.

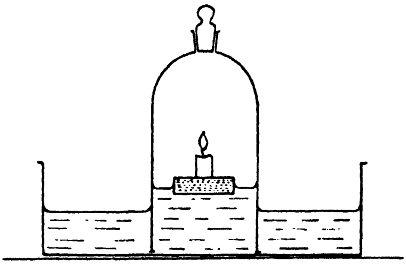


FIG. 54

A different experiment was made by John Mayow (*c.* 1674), which may be illustrated as follows. A lighted candle is put on a cork floating on water and over it is placed a large bell jar without its stopper (Fig. 54). The level of the water in the jar is marked and the stopper is put in. Very soon the water rises up the jar and in time the flame goes out. The candle in burning has used up part of the air, the water having risen to take its place.

About a hundred and fifty years ago a Swedish chemist, Scheele, burnt the substance phosphorus in a limited volume of air. (Yellow phosphorus is sold in yellow wax-like sticks. It must be stored in water because when it is dry and exposed to the air it bursts into flame. It must not be touched by the hand for the heat of the body sets it alight.) Scheele's experiment can be demonstrated as follows. A stick of phosphorus (while under water) is scraped clean and a piece about the size of a pea is cut off. This is fastened to the end of a long piece of copper wire (Fig. 55) which is then pushed to the end of a long graduated tube sealed at one end. The tube is then inverted in a tall jar of water so that the level of the water inside the tube is the same as that of the water in the jar. The air is then at atmospheric pressure and its volume is noted. Next day the reaction is practically complete and the water will

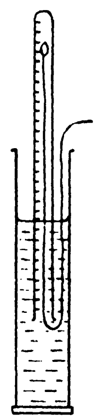


FIG. 55

have risen up the tube to take the place of the air which has been used by the smouldering phosphorus. The tube is moved so that the levels of the water in the tube and in the jar are the same and the volume left is recorded. It is found that about four-fifths of the original volume of air is left, one-fifth having been used by the phosphorus.

Scheele also showed that when iron rusts in air it uses part of the air. His experiment may be illustrated by placing clean, moistened iron filings in a muslin bag which is fastened to the end of a glass rod. The rod is then placed, as shown in Fig. 56, in a gas jar which is inverted over water. After some days the water will have risen about one-fifth the height of the jar.

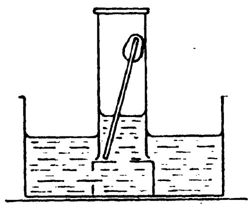


FIG. 56

Oxygen.—In these experiments one common observation is apparent, that when a candle or phosphorus burns, or when iron rusts, in a confined volume of air, about one-fifth of the air is used. This indicates that one-fifth of the air is different from the rest and is now known to be composed of the gas called oxygen. The discovery of oxygen was mainly due to the work of two scientists, an Englishman, Joseph Priestley (c. 1770), who was a nonconformist minister, and a Frenchman, Lavoisier, who was executed during the French Revolution. Priestley had been presented with a large magnifying-glass, which when held in the rays of the sun concentrated them to give a very hot spot (page 107), and used it to heat various substances in the laboratory (he had, of course, no coal gas or bunsen burners, etc.). One of the substances heated was the " red ash " of mercury which is formed when mercury is heated in air. He found that this substance gave off a gas (oxygen) in which a candle and other substances burned much more vigorously than they did in air. The experiment was later modified by Lavoisier, who heated mercury continuously for twelve days in a vessel containing 50 cubic inches of air. At the end of that time some of the mercury had changed to a red powder and 8 cubic inches of air had been used up. He then collected all the red powder, put it in a vessel and heated it, collecting all the air which was expelled. He collected 8 cubic inches and was left with the metal mercury instead of the red powder.

This experiment showed him that when mercury is heated in air it combines with part of the air to form a red powder and that when

this powder is heated, the same volume of air as combined with the mercury previously can be recovered.

The red powder is now known as mercuric oxide and the process can be represented thus:

(i) Mercury + Oxygen of the Air = Mercuric oxide;
(ii) Mercuric oxide = Mercury + oxygen.

Preparation of Oxygen.—This method of obtaining oxygen is largely of historical interest and other substances (which are cheaper) are now used. For example, the substance potassium chlorate slowly gives off oxygen when heated, but when it is mixed with about one-third of its weight of manganese dioxide, a black powder, and heated in a hard glass test-tube, oxygen is readily evolved and can be collected in gas jars over water as shown in Fig. 57. At

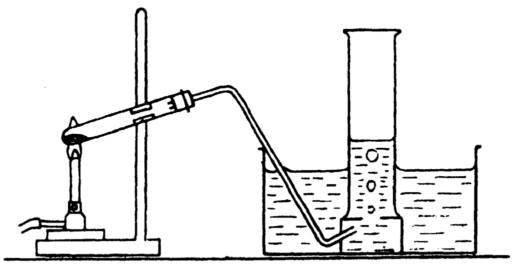


FIG. 57

the end of the reaction all the manganese dioxide can be recovered since none of it has been decomposed by the heat. Its purpose is to increase the speed at which the potassium chlorate gives off its oxygen (compare its use with the use of oil on the bearings of a machine: the oil is not used up although much is lost by being sprayed out of the machine. Or compare its use with a whip which increases the speed of a lazy horse!). Substances behaving like manganese dioxide are known as catalysts.

A catalyst is a substance which accelerates the speed of a chemical reaction or enables the reaction to take place at a lower temperature.

Thus:

Potassium chlorate + manganese dioxide =
Potassium chloride + oxygen + manganese dioxide.

Many of the properties of oxygen can be demonstrated by using the jars of oxygen collected by the method shown in Fig. 57.

The Properties of Oxygen.—

(*a*) It is a colourless gas, without taste or smell and slightly soluble in water.

(*b*) It re-lights a glowing splinter of wood—often with an audible pop.

(*c*) Joseph Priestley, in 1774, stated that " the dropping of a lighted candle into a jar of oxygen is a very beautiful experiment. The strength and vivacity of the flame is striking and the heat produced by the flame is also remarkably great."

Phosphorus, sulphur and charcoal are known as non-metals while iron and sodium are classified as metals for reasons given later (page 201) and it is important to notice how oxygen reacts with these two types of substances. This can be done by putting the burning substances in gas jars full of oxygen. Thus:

(*a*) Dry, yellow, feebly burning phosphorus burns with an intensely yellow flame.

(*b*) Feebly burning sulphur burns with a brilliant bluish flame.

(*c*) Glowing charcoal burns with a bright luminous flame.

(*d*) A small piece of sodium placed on the bowl of a deflagrating spoon, ignited, and put in a jar of the gas burns with an intensely hot yellow flame. (The metal calcium reacts similarly.)

(*e*) A bundle of thin iron wires, when heated to red-hotness and plunged into a jar of the gas becomes white hot and gives off numerous sparks.

Acids and Alkalies.—The above-named substances which burn in oxygen combine with the oxygen to form substances known as oxides, e.g. the oxide of phosphorus, of sulphur and of carbon, as well as the metallic oxides, sodium oxide, calcium oxide, iron oxide. The experiments mentioned above are usually done in gas jars of oxygen containing about 2 inches of water so that the oxides which are formed can be dissolved in the water if they are soluble and litmus, a vegetable dye, is put into the water. The solutions of the oxides of non-metals turn the litmus red whereas the solutions of the oxides of metals turn the litmus blue. Only a few metals, however, possess soluble oxides, e.g. sodium and calcium. The oxides of iron, copper, tin and most other metals are insoluble. A solution which turns litmus red is called an acid; one which turns it blue is called an alkali. Thus:

(*a*) Oxides of non-metals when dissolved in water form an acid solution, e.g. the oxides of phosphorus, sulphur and carbon.

(*b*) Soluble oxides of metals when dissolved in water form an alkaline solution, e.g. the oxides of sodium and calcium.

Preparation of Nitrogen.—The air consists of one-fifth by volume of oxygen and the remaining four-fifths is chiefly the gas, nitrogen. Impure samples of nitrogen can be obtained by burning a candle or phosphorus in a closed vessel of air, or by letting iron rust in such a vessel, since these substances combine with the oxygen of the air. A better method depends on the fact that the oxygen of the air combines with a metal, such as copper, but the nitrogen does not. The apparatus used is shown in Fig. 58. Copper turn-

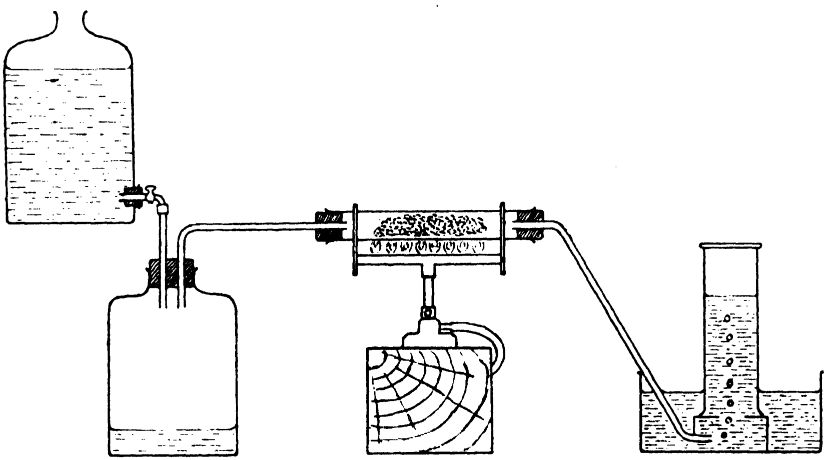


FIG. 58

ings are placed in the hard glass combustion tube, but before any gas is collected in the jar this tube is heated. Much of the air in it is thereby expelled and escapes forming bubbles in the water in the pneumatic trough. When no more bubbles are formed a gas jar full of water is then placed over the end of the delivery tube. Then the water is set dropping, very slowly, from the top aspirator into the bottom one. The water expels an equal volume of air, and this is forced over the copper which is still being heated. Provided that the air is passed slowly through the tube the oxygen in it combines with the copper, leaving the nitrogen to pass on and be collected over the water. The first jar to be filled is neglected, since it contains some air, but several other jars are filled to demonstrate the following properties.

Properties of Nitrogen.—

(*a*) it is colourless, tasteless and has no smell.
(*b*) a candle, phosphorus, sulphur and carbon will not burn in it.
(*c*) it has no action on litmus, or on lime water.

It can be regarded as a diluter of the oxygen and because of its presence the vigorous action of the oxygen in the air is toned down.

Rare Gases.—There are other gases in the air such as carbon dioxide, water vapour (page 85), and the rare gases, neon, helium, argon, xenon and krypton. These " rare gases " do not burn or combine in any way with other substances, that is, they are very inert. Helium does not occur in large quantities (about 5 parts in 10,000 parts of the air). Natural supplies of it are obtained in America, but in this country helium, like argon and neon, is obtained from the air. One of the uses of helium is given on page 65 ; argon is put in electric-light bulbs (page 225), and neon is used in the red electric advertising signs.

Manufacture of Oxygen and Nitrogen.—The laboratory methods of preparing oxygen and nitrogen have been mentioned, but these methods are not suitable for producing large supplies of them. A manufacturer likes to get his materials from as cheap a source as possible and the cheapest source of oxygen and nitrogen is the air.

When air or any gas is compressed and then allowed to escape through a very tiny hole it comes out cooler than it was at first and use is made of this fact in turning air into the liquid state. Liquid air is a mixture of oxygen, nitrogen and the rare gases, all in the liquid state, and it is extremely cold ($-190°$ C.). When it is fractionally distilled nitrogen is given off before the oxygen and can be collected separately.

The Uses of Oxygen.—Living creatures require oxygen and get it normally from the air, but when sufficient oxygen cannot be obtained in this way it has to be supplied. Thus :

(*a*) People suffering from complaints of the respiratory or breathing system, such as pneumonia, do not get an adequate supply of oxygen from the air they breathe and have to be given oxygen from cylinders containing the compressed gas.
(*b*) At high altitudes the air is sparse and aviators are sometimes supplied with oxygen from small cylinders.
(*c*) Oxygen is supplied in submarines and to rescue squads in mines and at large fires (the small cylinders are strapped on to the rescuer and a tube leads oxygen from the cylinder to a mask).

Courtesy of British Oxygen Co., Ltd.

FIG. 59
An Oxy-acetylene Welder at Work

Many gases which burn in air give a hotter flame when they burn in oxygen and special burners are used. Thus the flame produced by burning acetylene in oxygen is hot enough to melt iron and is used in welding. The photograph, Fig. 59, shows a man welding part of a car. The two cylinders, one containing oxygen and the other acetylene, can be seen as well as the special burner. He is directing the burner at the crack and the heat of the flame melts the iron. The molten liquid iron runs together and forms a solid piece when it cools.

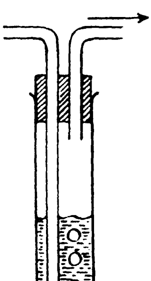


FIG. 60

Uses of Nitrogen.—Nitrogen is not used by itself for many purposes, but when it is combined with other substances it forms many very valuable products. Thus it is used in the manufacture of ammonia, nitric acid, artificial fertilizers and explosives.

Carbon Dioxide.—This gas plays an important part in plant and animal life, although the proportion of it in the

air is very low (0·03 per cent.). It can be made by burning carbon in oxygen but a pure sample of the gas is not obtained. When it is required in the laboratory it is made by another method (page 176). The gas has a distinctive property by which it can be recognized ; it turns lime-water milky (page 175 and its presence in air can be shown by drawing air for a few minutes through a tube containing lime-water (Fig. 60).

CHAPTER VIII

WATER

MOST metals have little apparent action on cold water, but there are three, sodium, potassium and calcium, which react vigorously with it. These three metals are rarely seen outside a laboratory.

Calcium and Water.—Calcium is not a very common metal and has few uses outside the laboratory. It is sold in sticks about 2 inches in diameter which can be sawn into small pieces. A piece of the metal about the size of a bean is put under a jar full of water in a pneumatic trough (Fig. 61). The metal, being heavier than water, sinks. A gas called hydrogen is given off and collected in the jar. It will be found that the gas burns with a bluish flame.

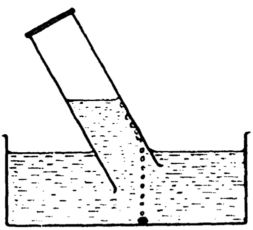


FIG. 61

When litmus is added to the water in the trough it is turned blue, so that the solution in the trough is alkaline. It will be recalled that the oxides of certain metals, of which calcium is one, yield alkaline solutions with water (page 56).

Sodium and Water.—This experiment can be repeated using the metal sodium. This metal is, however, lighter than water and hence floats. It may be enclosed and sunk in a little cage made of wire gauze and the rest of the experiment carried out as before. There is, however, a danger of an explosion, and a safer method is to act on water with sodium amalgam, a substance made by dissolving sodium in mercury. (Potassium reacts even more vigorously and when a piece of it is thrown into a trough of water sharp explosions are heard and the hydrogen which is given off burns with a lilac-coloured flame.)

Iron and Steam.—Iron does not decompose cold water, indeed before iron and water react the iron must be red hot and the water

in the form of steam. The apparatus used for this reaction is shown in Fig. 62. The long tube is made of iron or gun-metal and is about half filled with bright iron nails. A combustion furnace is necessary to make the iron red hot.

The water in the flask is boiled and steam is passed over the red-hot iron. Any excess of steam condenses in the cold water in the trough and the gas, which is hydrogen, is collected in the gas jar. But since the apparatus was full of air at the beginning of the experiment the first jar to be filled is discarded. Many gas jars of hydrogen can be obtained and the gas examined. It will burn with a bluish flame with a slight "pop." The nails, when they have cooled, have lost their brightness and they are covered

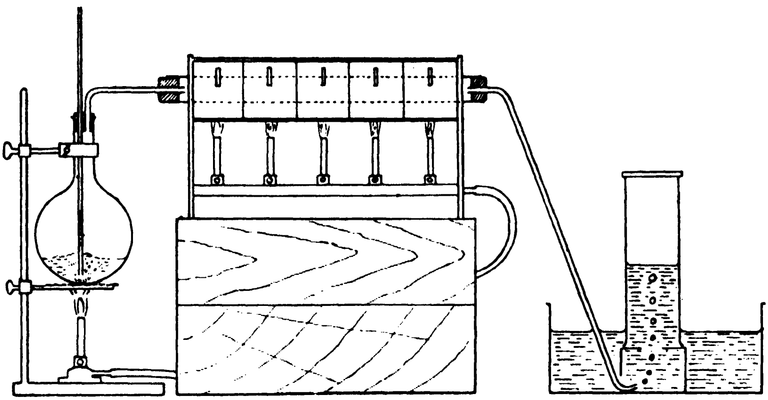


FIG. 62

with a substance known as iron oxide. (The metals magnesium and zinc, when heated, also react with steam to give the oxide of the metal and hydrogen. But copper and the noble metals have no action on water or steam.)

Composition of Water.—Hydrogen can, therefore, be obtained by acting on water with certain metals. No matter what experiments are done hydrogen cannot be obtained from a metal only and it must therefore have come from the water. In each case, the oxide of the metal was formed. Again, it is impossible to get oxygen from a metal by itself and it too must have come from the water. Possibly water is made of these two gases. Before this can be shown it is desirable to have a more convenient method of preparing hydrogen.

Laboratory Preparation of Hydrogen.—A layer of granulated zinc is put into a flask fitted with a rubber stopper, thistle funnel and delivery tube (Fig. 63). Dilute sulphuric acid is poured down the thistle funnel, and effervescence takes place. Hydrogen is given off, but is not collected in the jar until it has been tested by putting a test-tube over the end of the delivery tube and, when it is full, applying a light to the gas. When the gas so collected burns only with faint " pop " it is known that all the air originally in the apparatus has been driven out and the hydrogen—which is known to be air-free—is collected in gas jars over water.

Much heat is given out by the reaction and the flask will be quite warm at the end of the experiment. Some of the solution in the flask can then be evaporated in a basin, a glass rod being dipped occasionally in the solution, withdrawn and the drop of solution allowed to cool. When a misty appearance is produced on the rod on cooling, the whole of the solution is put on one side to cool and in time a crop of white crystals will be obtained. These are crystals of a substance known as zinc sulphate. Thus:

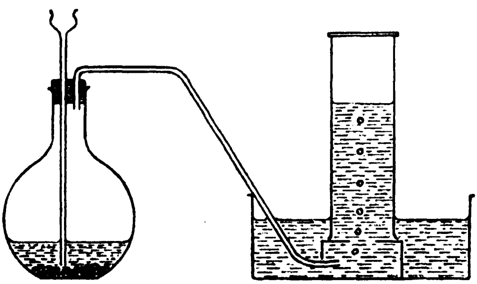


FIG. 63

Zinc + Sulphuric Acid = Zinc Sulphate + Hydrogen.

Properties of Hydrogen.—

(*a*) It is a colourless, tasteless gas with no smell.

(*b*) It burns with a blue flame. (To see the true colour of the flame the hydrogen should be burned as it emerges from a platinum jet since glass colours the flame yellow.)

(*c*) It forms an explosive mixture with air or oxygen.

(*d*) It is lighter than air (its density is 1; that of air is 14·4). This can be shown by standing upright a jar of the gas with the cover-slip removed; in a few minutes' time there will be no " pop " if a light is put to the contents of the jar, all the gas having risen into the air. A balloon, or soap bubble filled with the gas quickly rises into the air when released.

The Synthesis of Water.—The aim of the experiment is to show that water is formed when hydrogen burns in air and therefore it is essential to make sure that there is no water present in the gas to begin with. It must be remembered that the hydrogen prepared by zinc and dilute sulphuric acid contains water vapour, for it has had to pass through an aqueous solution in the flask. The apparatus used is shown in Fig. 64. The **U** tubes contain fused calcium chloride which substance combines with the water vapour in the gas. The hydrogen issuing from the jet is tested for absence of air and then lighted. The flame impinges on the surface of a retort, which is kept cool by running cold water through it. Drops of a liquid collect on the surface and finally

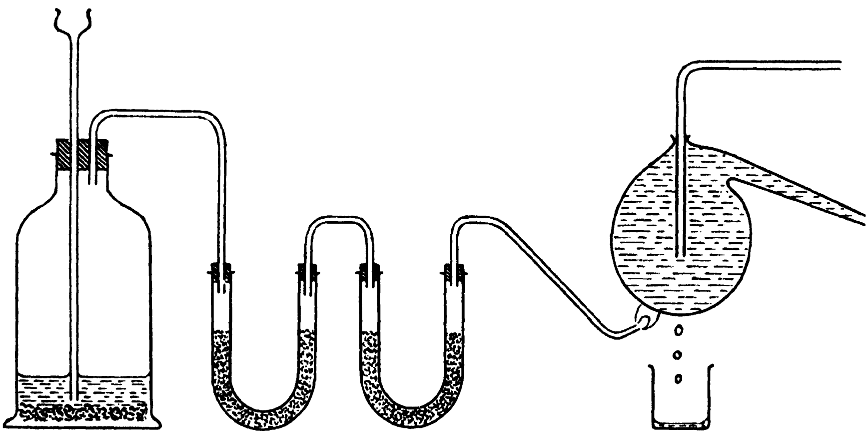


FIG. 64

drop into the receiving vessel. This liquid can be shown to be water by adding white anhydrous copper sulphate to it. Water —or an aqueous solution—is the only liquid which turns anhydrous copper sulphate blue and the liquid obtained by burning hydrogen in air turns it blue. Hydrogen, in burning, combines with the oxygen of the air to form water, which is the oxide of hydrogen.

When oxygen is mixed with exactly twice its volume of hydrogen and the mixture is exploded by an electric spark, water is formed and nothing else remains. If the explosion tube is hot enough steam is formed and experiments show that:

2 volumes of Hydrogen + 1 volume of Oxygen yield 2 volumes of Steam.

Hydrogen has a powerful affinity for oxygen (that is, it readily

combines with it), and when it is passed over many heated metallic oxides it combines with the oxygen of the oxide to form water and leaves the metal. This can be illustrated as follows: Black copper oxide is put in a combustion tube and dry hydrogen is passed through the tube until all the air is expelled. The oxide is then heated. Soon the black colour has changed into the brown colour of copper and moisture has condensed on the cold parts of the tube.

Copper Oxide + Hydrogen = Copper + Water.

Oxidation and Reduction.—It has been seen that many metals and non-metals combine with oxygen to form oxides and such substances are said to be "oxidized." Thus:

Oxidation is a process whereby oxygen is added to a substance. Examples are the oxidation of iron to iron oxide or rust, copper to copper oxide, carbon to carbon dioxide, phosphorus to the oxide of phosphorus and sulphur to sulphur dioxide.

The removal of oxygen from copper oxide by hydrogen is the reverse of this process and is known as reduction. Thus:

Reduction is the process whereby oxygen is removed from a substance.

Hydrogen reduces copper oxide, and water (or hydrogen oxide) is formed. That is, the hydrogen has been oxidized, whereas the copper oxide has been reduced. Oxidation and reduction usually take place at the same time, the reducing agent being oxidized and the oxidizing agent being reduced.

Many other oxides of metals are reduced by hydrogen, e.g. iron oxide and lead oxide. Other substances, such as carbon, and the gas, carbon monoxide, act as reducing agents. These will be mentioned later.

Manufacture of Hydrogen.—One method is by the reaction of steam on red-hot iron (see page 60). It is also made by blowing steam through white-hot coke when a mixture of hydrogen and the gas, carbon monoxide, is formed. This mixture is known as water-gas. It is mixed with more steam and passed over a catalyst. The carbon monoxide is then oxidized to carbon dioxide but the hydrogen is unchanged. (Hydrogen can be separated from carbon dioxide much more easily than it can from carbon monoxide.)

Electrolysis of Water.—Another method of manufacturing hydrogen can be illustrated by using the apparatus known as the

voltameter (Fig. 65). This is filled with water to which a little dilute sulphuric acid has been added and the taps are closed. The piece of platinum at the bottom of one of the side limbs is connected to the positive pole of an accumulator and is known as the anode; the other is connected to the negative pole and is known as the cathode. Bubbles of hydrogen are given off at the cathode and of oxygen at the anode. It is found that the volume of hydrogen is twice that of the oxygen. (It will be remembered that the volume composition of water is two volumes of hydrogen to one of oxygen.)

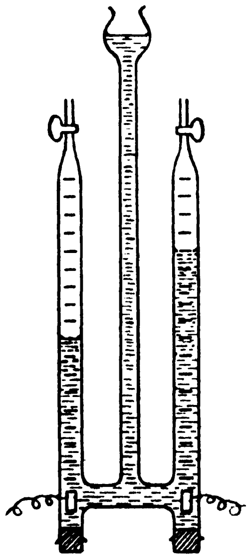


FIG. 65

Uses of Hydrogen.—Many tons of the gas are used annually for various purposes. It is the lightest gas known, being over fourteen times lighter than air and hence it is used for filling airships and balloons. But it is very inflammable and many disastrous fires have destroyed airships filled with it, often with great loss of life. Hence it is being replaced by helium, particularly in America where natural supplies of helium are found. Helium, however, although non-inflammable is twice as dense as hydrogen and its lifting power is therefore not so great.

Natural solid fats are obtained from animals and are much dearer than oils, i.e. liquid fats, which are obtained from fish and from vegetable sources, e.g. olive oil, palm oil, and ground-nut oil. Hydrogen is passed into a mixture of the boiling oil and powdered nickel. The mixture is filtered, to remove the nickel, and when it has cooled a solid fat is formed. This fat is then used to make margarine.

Hydrogen is now used to make motor spirits and the heavy motor oils. These are obtained when the gas reacts with coal dust under certain conditions. Large quantities are also used in the manufacture of ammonia (page 198).

CHAPTER IX

MOLECULES AND ATOMS

THERE is a wonderful variety of materials and substances available to satisfy the needs of modern life, but this has not always been so. Primitive man lived a very simple life, his needs being met by the substances near at hand, such as wood and stone and the carcasses of animals. As civilization advanced the increased range and facility of transport made available for use those natural substances which were only to be found in a few places in the world. Also from these natural substances or raw materials it was found that new substances could be artificially produced and modern science has greatly added to their number. The thousands upon thousands of different substances in the world to-day are built up of a relatively few simple substances.

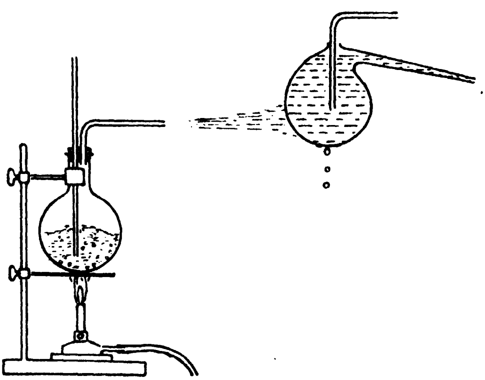


FIG. 66

When water is boiled in the apparatus shown in Fig. 66 nothing is seen in the upper part of the flask, in the outlet tube, or even for a little distance from the end of this tube. Yet water collects on a cold surface placed near the outlet tube as shown. It must have been transferred from the boiling water through the apparently empty space which obviously contains water moving through it in an invisible form. Heating changes the water into a steam, a gas which when cooled condenses and re-forms water. The apparently empty space in the apparatus is full of invisible steam which condenses on coming into the cold air

into tiny droplets of water. Thousands of these droplets form the "cloud of steam."

Water can be turned into steam by heating it, and into ice by freezing it, and chemical analysis shows that ice, water and steam are alike in composition, all three being made of hydrogen and

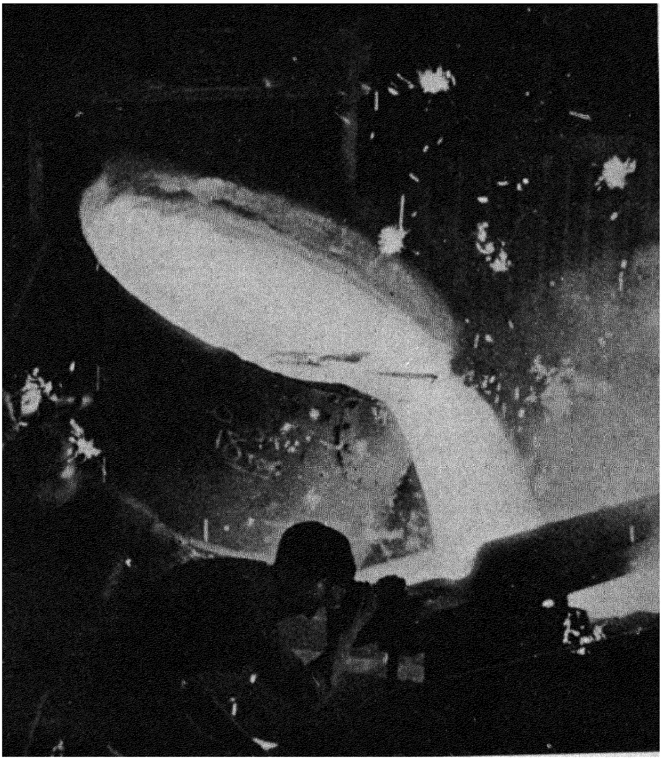


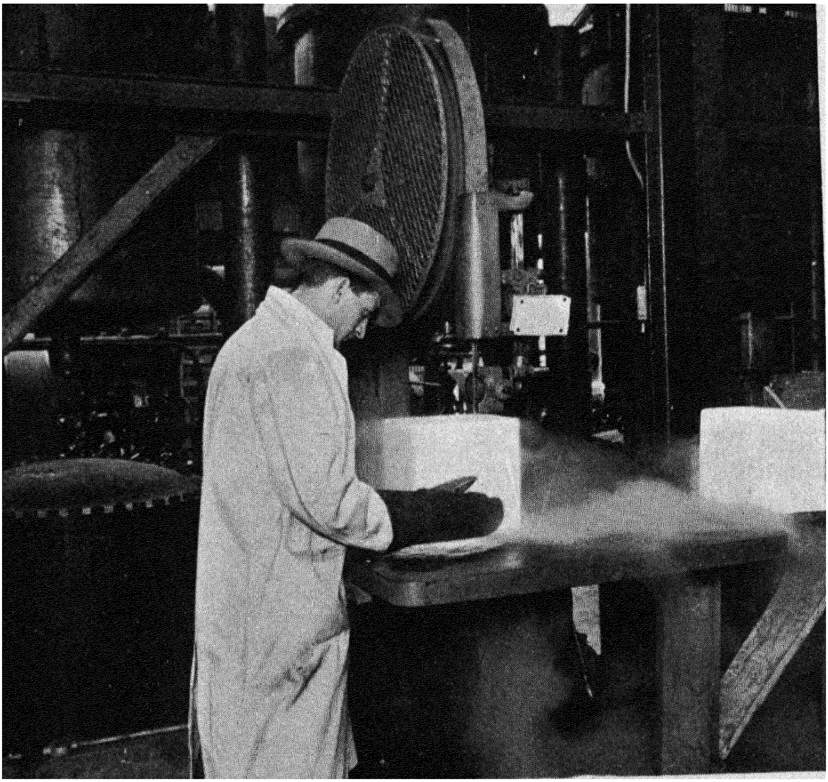
Photo: A. King

FIG. 67

A Ladle of Molten Iron

oxygen. Water is a substance which can exist as a solid, liquid or gas, and many other substances resemble it in this respect. These three "states of matter" can usually be changed the one into another by a change in temperature. Iron and most metals melt when heated, and the photograph (Fig. 67) shows liquid or molten iron being poured into a mould. Air can be liquefied (page 67) and turned into a solid as can other gases. For example, solid

carbon dioxide is now a fairly common substance and is much used for freezing substances. The photograph (Fig. 68) shows a block of it being cut. It is a white solid and is often called carbon dioxide snow.



Courtesy of Solvent Products Ltd.

FIG. 68

Sawing a Block of Solid Carbon Dioxide

Molecules.—It seems strange that the same substance can exist as a solid, liquid or gas, and to understand this it is necessary to realize something of the make-up of substances. The apparently empty space (Fig. 66) was full of steam consisting of very small particles of water very much too small to be seen by the naked eye. These particles, when cooled, coalesce and form the liquid, that is, some of them join together and a particle large enough to be seen is

formed; the cloud of steam contains thousands of these larger particles. Gases are made up of tiny particles much too small to be seen even under the most powerful microscope. The particles of one gas, however, are different in many ways from the particles of another. The smallest possible particle which can have independent existence is known as a molecule. These molecules are so exceedingly tiny that the tiniest visible droplet of water obtainable consists of millions of them.

A molecule is the smallest particle of matter which has free existence.

Solids, Liquids and Gases.—Gases, then, can be pictured as consisting of millions upon millions of these molecules which are moving at great speeds. In many ways a gas resembles a swarm of insects, such as midges, which are darting about in the sunlight. The molecules, too, dart and dash about in every direction, colliding and rebounding with each other. If a few bees are put in an empty hive, before long they will have found their way into every part of it and, similarly, when a gas is put into a vessel very soon its molecules will have spread to every part of it. A gas fills all the space that is given to it and has no fixed volume, size or shape of its own. When a gas is heated the molecules move faster than they did before. If the space is restricted, e.g. if a gas is heated in a closed flask, the increased speed of the molecules causes an increase in the number of collisions made by the molecules against the wall of the flask. That is, the pressure increases and in time may become great enough to burst the flask. Conversely, when the gas is cooled the speed of the molecules decreases and instead of rebounding they coalesce and particles containing more than one molecule are formed. In time these particles grow and drops of liquid are formed which collect on the sides of the vessel. A liquid does not occupy all the space given to it, as a gas does, but has a definite volume. There is some freedom of movement of the molecules possible, however, for the liquid can be poured. The molecules then slide over each other just as the grains of sand do when sand is poured from one vessel to another. Just as the particles of sand settle to the shape of the vessel into which they are poured, so do the molecules of a liquid. Although a liquid has a definite volume, it has no shape of its own but takes the shape of the containing vessel.

A solid is formed when a liquid is cooled and the freedom of movement of the molecules is further restricted. The molecules

adhere to each other and therefore a solid has a definite size and shape.

The molecule of a substance has a definite weight, and since the molecules are more closely compact in the solid and liquid states than in the gaseous state equal weights of the same substance have different volumes in the solid, liquid and gaseous states. Actually this difference is very small between the solid and liquid states (indeed a gram of the solid substance sometimes occupies a greater volume than a gram of the liquid form of the same substance, e.g. ice and water, page 84). But an equal weight of the gaseous substances occupies a much greater volume; a volume of water yields about fifteen hundred times the same volume of steam. This volume depends on the external pressure as do all gaseous volumes.

Surface Tension.—The molecules of a liquid are closely packed together and attract each other. Thus the molecules at the surface of the liquid are tightly held together by the attraction of those within the surface, forming, as it were, a skin on the surface. This skin can support small weights. Thus a needle can be floated on the surface of water by putting it first on a piece of paper, then laying the paper on the surface of the water, afterwards carefully withdrawing it. Also if a small object is slowly and carefully put in a tumbler brimful of water the water rises above the level of the brim and appears to be held in place by a skin. A free liquid surface always tends to shrink to the smallest possible area. This property, which is possessed by all liquids, is said to be due to surface tension. Owing to the effects of surface tension a small drop of liquid always tends to assume a spherical shape if there are no forces influencing it, for the surface of a sphere is smaller than that of any other shape of the same volume. The tiny drops of mercury seen when the liquid is spilled take the shape of a sphere, though the bigger drops are flattened for their weight is greater. Rain-drops are spherical in shape owing to the effect of surface tension. The bristles of a paint-brush are quite free from each other when the brush is in the paint, but when the brush is pulled out the bristles cling together owing to the tendency of the liquid paint to form as small a surface area as possible. Hence the paint remains on the brush and does not drop off. The surface skin of water is strong enough to support the weight of small insects which can walk about on it. It also supports the larvæ of the mosquito and other insects.

Capillary Attraction.—Fig. 69 shows two tubes which have been placed in water; the water has risen some distance up each

tube ; the narrower the bore of the tube the farther the water rises. This capillary attraction is another effect of surface tension. The downward curved surface can be compared with a stretched skin supporting a weight hanging from it. Capillary action is of great importance in Nature and is one of the reasons why water ascends the stem of the plant once it has entered the root. Water spreads through the soil, oil rises up the wick of a lamp, water soaks into clothes, ink into blotting-paper, and water into a towel by capillarity.

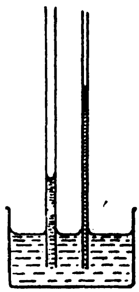


FIG. 69

Effect of Pressure on a Gas.—When pressure is exerted on a gas the molecules are forced closer together and occupy a smaller volume. This can be demonstrated by the apparatus shown in Fig. 70. Mercury is added to the **J** tube until it is level in each limb. In this way air is entrapped in the closed limb and is at atmospheric pressure. More mercury is poured into the open limb, so increasing the pressure on the enclosed air. If the difference in the levels of the mercury is 30 inches, there will be a pressure on the enclosed air equal to two atmospheres, i.e. the atmospheric pressure on the surface of the mercury, plus the pressure due to the column of mercury 30 inches high (which is equivalent to the pressure of one atmosphere, page 44). It will be found that the air in the enclosed limb has been compressed to half its original volume. Similar experiments show that the volumes of the gas are inversely proportional to the pressures exerted on it. This was discovered by Boyle and he formulated the facts into a statement known as Boyle's Law.

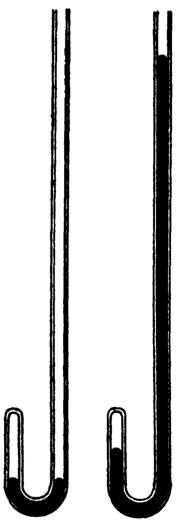


FIG. 70

At a constant temperature, the volume of a gas varies inversely with its pressure. (The law is approximately true only for relatively low pressures of a few atmospheres.)

Atoms.—It has been mentioned that molecules of one substance differ from molecules of another and to explain this difference the structure of a molecule must be considered. For although a molecule is the smallest part of matter which can exist independently it

is not the smallest particle known to science. Indeed, molecules are made of still smaller particles known as "atoms" and each molecule of many simple gases, such as oxygen, is made up of two atoms. But there is this important difference between an atom and a molecule. As a general rule an atom cannot exist by itself, whereas a molecule can.

Atoms may be regarded as the chemical "bricks" from which all substances are made. Water, for example, is formed when a mixture of hydrogen and oxygen molecules is exploded. A molecule of it contains three atoms (bricks), one of oxygen and two of hydrogen. Water molecules therefore contain two kinds of matter, oxygen matter and hydrogen matter. Copper forms copper oxide when it is heated in air; again combination of two kinds of matter has taken place and each molecule of the copper oxide consists of an atom of copper and an atom of oxygen. Numerous other examples can be mentioned of molecules containing two or more different atoms, e.g. a molecule of carbon dioxide contains an atom of carbon and two atoms of oxygen; a molecule of iron oxide contains two atoms of iron and three atoms of oxygen; a molecule of copper sulphate is built up of one atom of copper, one atom of sulphur and four atoms of oxygen.

Elements and Compounds.—It is apparent, by now, that there are two kinds of molecules. Examples of the first type are molecules of oxygen, hydrogen, nitrogen and phosphorus, each of which is made of atoms of one kind only. These substances are known as elements. A molecule of certain other substances, e.g. water, carbon dioxide, copper oxide, iron oxide, copper sulphate, contains two or more different kinds of atoms and these substances are known as compounds. Thus:

An element is a substance whose molecules are composed of the same kind of atoms.

A compound is a substance whose molecules are composed of two or more different kinds of atoms.

There are only about ninety different elements and therefore ninety different atoms known to science, and out of this small number the many thousands of different substances are made. If there were large numbers of each of ninety different kinds of bricks thousands of different buildings could be made. Some of these would be made of bricks all of the same kind, others might be built of two, three or four . . . different kinds. Similarly out of the

ninety different atoms thousands of different substances can be made ; many substances, however, contain only a few—two, three or four—different kinds of atoms.

Although atoms can be regarded as the " chemical bricks " out of which molecules can be built, the analogy must not be pushed too far. For example, atoms cannot exist by themselves and a particular atom only combines with certain other atoms. The building of chemical molecules either by Nature or artificially by man, is not a haphazard process and chemists can predict whether two or more different atoms are likely to combine in addition to stating what kind of substance will be formed when combination takes place.

Compounds and Mixtures.—When one element combines with another a chemical change is said to have taken place. A chemical change also takes place when a compound combines either with another compound or with an element. But it must not be assumed that two or more elements will necessarily combine when added together. More frequently they do not, especially if they are not heated or otherwise made to react. Neither does chemical change always take place when compounds are added to each other. In the case of both elements and compounds the substances may remain simply mixed. Indeed some substances will not even mix with certain other substances (oil will not mix with water), but this is not a common occurrence. All gases mix intimately and it is not easy to separate them.

These facts may be summarized thus :

When two or more substances are added together they may

(*a*) react chemically with each other, combination taking place with the formation of one or more compounds,
(*b*) mix, forming a " mixture,"
(*c*) neither mix nor react with each other.

The following experiment illustrates many important differences between a mixture and a compound each made from the same elements. Iron filings are passed through a fine sieve and mixed in a mortar with half their weight of finely powdered roll sulphur. The mixture is divided into two parts, one of which is put on one side for the moment while the other is put in a test-tube. The tube is heated gently at the bottom ; soon a glow appears ; the bunsen is removed but the glow continues and spreads throughout the whole of the mixture. (There is a smell of sulphur and the blue flame of burning sulphur can be seen.) When the reaction is finished and the

tube has cooled, the contents, a compound called ferrous sulphide, are removed and compared with the mixture of iron and sulphur which was put on one side. They differ in colour, the mixture being approximately intermediate in colour between the iron and sulphur, but the compound is black. When the mixture is examined through a powerful lens particles of iron can be seen as well as particles of sulphur. But no particles of iron or sulphur can be seen in the compound. If the mixture is put in a beaker of water, stirred and allowed to settle, some separation occurs and particles of sulphur float on the surface while the heavier iron sinks to the bottom. The compound, on the other hand, sinks and no separation of the iron and sulphur takes place. The iron can be separated from the mixture, but not from the compound, by drawing a magnet through it and then blowing off the particles of sulphur which adhere to the iron. The sulphur of the mixture, but not of the compound, can be separated by adding a liquid called carbon disulphide to it, which dissolves sulphur but not iron.

Another difference in the two can be shown by adding dilute hydrochloric acid to each. The mixture gives off hydrogen whereas the compound gives off a different gas which has the smell of rotten eggs and is known as hydrogen sulphide.

It is apparent from this that the mixture has the properties of both iron and sulphur whereas the compound has properties of its own, many of which are entirely different from those of its constituents. Indeed, the compound is an entirely different substance from either the iron or the sulphur.

Physical and Chemical Changes.—This formation of a different substance is one of the characteristics of a chemical change and in this and other respects such changes differ from another kind of change called a Physical Change. Typical physical changes take place when

(*a*) ice is heated, forming water, which when heated forms steam. Conversely when steam is cooled water is formed which when frozen yields ice,
(*b*) an electric current is passed through a copper wire,
(*c*) iron is magnetized,
(*d*) gold is heated in air until it becomes red hot.

Chemically, ice, water and steam are each the same substance, as can be proved by analysing them. The passage of the electric current does not change the copper into a different substance.

Iron is not changed into a different substance on being magnetized, neither is gold on being heated. Moreover, when steam is cooled it re-forms water; the copper is left unaltered when the current is switched off; iron remains when the magnetized iron loses its magnetism; and gold is left when the red-hot gold is cooled. Furthermore, when any of the changes mentioned take place there is no change in weight; one pound of ice yields one pound of water or one pound of steam; copper does not increase in weight on being electrified, nor does iron on being magnetized nor gold on being heated.

Contrast these with the following chemical changes:

(*a*) when wood or a candle is burnt,
(*b*) when mercury, magnesium or any base metal is heated in air.

In each case different substances are formed; wood forms smoke and leaves an ash; the candle forms fumes; the heated mercury, magnesium or any base metal forms ashes or oxides. If the products of the burning wood are collected it is impossible to re-form wood from them, as it is also impossible to re-form a candle from its fumes. It is not an easy matter to obtain the metal and oxygen from, say, magnesium oxide or from most of the metallic oxides (mercuric oxide acts exceptionally in this respect).

Furthermore, one gram of magnesium does not yield one gram of magnesium oxide, but there is a change in weight which is not haphazard, for a definite weight of magnesium always combines with a definite weight of oxygen to form the oxide. This occurs no matter how much oxygen is in excess. A definite weight of any one element always unites with a definite weight of another to form a compound (see page 78).

The difference between chemical and physical changes may be summarized thus:

Physical Changes.	Chemical Changes.
(*a*) The substance undergoing the change is not converted into a different substance.	(*a*) The substance, or substances, undergoing the change are converted into different substances.
(*b*) When the conditions of the change are reversed the substance is brought back to its original state or condition.	(*b*) The original substances cannot, as a rule, be obtained from the products of the change by reversing the conditions. In many cases it is an extremely

Physical Changes.	Chemical Changes.
	difficult matter to get back the original substances by any method.
(*c*) There is no loss or gain in weight during a physical change.	(*c*) A certain weight of one substance always combines with a definite weight of another to form a certain compound.
	(*d*) In some changes heat is given out and occasionally light and sound.

The chief differences between mixtures and compounds are shown below:

Compounds.	Mixtures.
(*a*) They are formed as the product of chemical change.	(*a*) No chemical change occurs in their formation.
(*b*) Different samples of the same compound have a constant and definite composition by weight. It is homogeneous (one part is like any other).	(*b*) The composition of a mixture may vary in different samples of the same mixture. It is not necessarily homogenous (one part is not like any other).
(*c*) The constituents of a compound can be separated only by means of a chemical change and not by mechanical methods.	(*c*) The constituents can usually be separated by mechanical methods.
(*d*) The compound has usually entirely different properties from its constituents.	(*d*) Each constituent of a mixture retains its own properties.

Symbols.—The earlier chemists used cumbersome symbols instead of the names of elements. These were difficult to write, print and remember, and to-day the initial letter of the Latin name of the element is generally used. When two elements have names beginning with the same initial letter one other letter from the name is added to the initial one. The initial letter is always put as a capital and the next letter as a small one. The symbol, besides representing the name of the element, represents a definite amount of it—one atom. Thus " O " represents an atom of oxygen, " H " an atom of hydrogen, " C " an atom of carbon and " Cu " one of copper (the Latin for copper is cuprum). A list of symbols of common elements is given in Table I.

TABLE I

Element.	Symbol.	Element.	Symbol.
Aluminium	Al	Mercury [4]	Hg
Bromine	Br	Nitrogen	N
Calcium	Ca	Oxygen	O
Carbon	C	Phosphorus	P
Chlorine	Cl	Potassium [5]	K
Copper [1]	Cu	Silver [6]	Ag
Hydrogen	H	Sodium [7]	Na
Iron [2]	Fe	Sulphur	S
Lead [3]	Pb	Tin [8]	Sn
Magnesium	Mg	Zinc	Zn

The Latinized names are (1) Cuprum, (2) Ferrum, (3) Plumbum, (4) Hydrargyrum, (5) Kalium, (6) Argentum, (7) Natrium, (8) Stannum.

Formulæ.—Molecules are composed of atoms and the symbols of the atoms of the constituent elements are used for the formula of the molecule. In England, chemists indicate the numbers of atoms in a molecule by placing a small figure to the right of the symbol at a slightly lower level. Thus O_2 represents a molecule of oxygen and indicates that such a molecule contains two atoms while P_4 stands for a molecule of phosphorus which contains four atoms.

Compounds are formed by the union of atoms of two or more elements and the formula of a compound represents one molecule of the compound and indicates its composition. Thus H_2O represents one molecule of water and indicates that such a molecule contains two atoms of hydrogen united with one atom of oxygen.

Law of Conservation of Matter.—Scientists have discovered certain facts and have expressed their interpretation of these facts in statements which are known as laws. One of the most important of these laws is the Law of Conservation of Matter which states that matter cannot be created or destroyed. Matter can be changed, as it is when a chemical change takes place, for then one substance is converted into another. But the combined weight of the substances which react is the same as that of the products. This does not always appear to be so. For example, a candle appears to burn completely away, but the smoke and gases, etc., which are given off weigh exactly the same as the candle and the oxygen it used up in burning.

Atoms and Molecules.—John Dalton, an English scientist, did much to advance the subject of chemistry by his Atomic Theory.

He stated, for example, that atoms of one element are all alike in size and weight but that they differ from atoms of other elements. Dalton knew that the weight of a single atom was exceedingly small and he had no method of finding it. Yet he realized the importance of being able to compare the weights of atoms of different elements. Hydrogen is the lightest element and he therefore compared the weight of all other atoms with that of the weight of an atom of hydrogen; the value he so obtained he called the atomic weight.

The atomic weight of an element is the number of times heavier an atom of that element is than an atom of hydrogen.

The molecular weight of a substance is the sum of the atomic weights of all the atoms comprising the molecule and so it is the number of times a molecule of the substance is heavier than one atom of hydrogen.

Dalton also stated that during chemical combination atoms of different elements combine to give compounds. An atom of copper combines with one of oxygen to give a molecule of copper oxide. Since each of these two atoms has definite weight it follows that definite weights of oxygen combine with definite weights of copper. This fact is expressed in Dalton's Law of Definite Proportions.

Law of Constant and Definite Proportions.—A compound is formed by the union of its constituent elements in a constant and definite proportion by weight, or, more briefly,

The weight composition of a compound is constant.

This law states, in effect, that no matter how a compound is formed, whether in Nature or artificially, it is always formed of the same elements united together in the same proportions by weight. It can be illustrated by preparing specimens of copper oxide using as many different ways as possible, e.g. by heating powdered copper in air, by heating either the nitrate or the carbonate until no further loss in weight occurs. Each of the three specimens so obtained is then analysed by heating a known weight of the oxide in a stream of hydrogen gas. The hydrogen converts the oxide to the metal.

Copper Oxide + Hydrogen = Copper + Water.

The amount of copper left is found by weighing it and the loss in weight gives the weight of oxygen with which the weight of copper was combined. It will be found, no matter by what method the copper oxide has been prepared, that the proportion by weight of the copper to the oxygen is always 63·5 of copper to 16 of oxygen

(the atomic weights of copper and oxygen are respectively 63·5 and 16).

Equations.—It is convenient to express most chemical changes by means of " equations " using the formulæ of the various chemical substances concerned. The formula of a substance represents one molecule and indicates a definite weight. The equation for the action of hydrogen on copper is:

$$CuO + H_2 = Cu + H_2O.$$

and this indicates that one molecule of copper oxide reacts with a molecule of hydrogen to produce an atom of copper and a molecule of water. (It is assumed, in equations, that molecules of metals contain one atom.) The equation for the formation of water is

$$2H_2 + O_2 = 2H_2O,$$

which indicates that two molecules of hydrogen unite with a molecule of oxygen to form two molecules of water.

CHAPTER X

HEAT

CAREFUL consideration is given in many industries to ensure that the best value for money, from a heat standpoint, is obtained when purchasing fuels. For example, coal at £2 a ton may be more economical than coal at thirty shillings, for it might yield more than one and a third times the quantity of heat. A thousand cubic feet of gas at four shillings may be cheaper than an equal volume at three shillings and sixpence since coal-gas varies considerably in its heating power. From this standpoint alone some method of estimating the quantity of heat given out is desirable. Before this can be done it is necessary to define what is meant by "unit quantity" of heat, and this can be illustrated by an experiment. A bunsen-burner, which has been regulated to give a steady flame (which will therefore give out the same amount of heat each minute), is put to heat one pound of water until the temperature of the water increases, say, 20° F. The time taken to do this is noted. The experiment is then repeated, using two pounds of water instead of one. It will be found that the time taken is just twice as long. Another experiment is done in which one pound of water is heated over the same flame until its temperature increases 40° F., i.e. twice that in the first experiment. It will be found that the time taken is again twice as great as the first time. These experiments show that the quantity of heat required depends on the weight of the water and the increase in temperature. These two facts are used in measuring quantities of heat. The unit used in industry in England is called the British Thermal Unit.

The British Thermal Unit (B.Th.U.) is the amount of heat required to raise one pound of water through 1° F.

Large heat quantities are often expressed in "therms," one therm being equal to 100,000 B.Th.U.

A different unit called the calorie is used in scientific work.

A calorie is the amount of heat required to raise one gram of water through $1°$ C.

A larger unit, known as the big, or great, or large calorie and represented by a capital C is sometimes used

$$1 \text{ Calorie} \equiv 1{,}000 \text{ calories.}$$

The quantity of heat needed for certain purposes can readily be calculated, e.g. find the quantity of heat, in calories, needed to raise 200 grams of water from $21°$ C. to $61°$ C., i.e. through $40°$ C. Heat required to raise—

1 gm.	of water	$1°$ C.	=	1 calorie
200 gms. ,,	,,	$1°$ C.	=	200 calories
,, ,, ,,	,,	$40°$ C.	=	$200 \times 40 = 8{,}000$ calories.

Working similarly with the weight in pounds and temperature-change in ° F. the quantity of heat may be found in B.Th.U.

A similar calculation can be made to calculate the heat given out by water when it cools. In this case the fall in temperature takes the place of the rise in temperature. Thus, when 300 grams of water cool from $100°$ C. to $20°$ C., i.e. $80°$ C. :—

Heat given out when	1 gm.	cools	$1°$ C.	= 1 calorie.
,, ,, ,, ,,	300 gms.	,,	$80°$ C.	= 300×80 calories.

It will be noticed from the examples that :

The quantity of heat taken in or given out by water
$$= (\text{weight}) \times (\text{change in temperature}).$$

Use is made of these units in determining and expressing the heating value of fuels ; this value is frequently termed the calorific value.

Calorific Value.—The calorific value of a fuel is the quantity of heat which can be obtained from a unit quantity of substance when completely burnt. For example the calorific value of coal is about 14,000 B.Th.U.s per pound and that of gas about 475 B.Th.U.s per cu. ft. (These values are only approximate ones, for they very largely depend on the quality of the fuel.) Large users of coal often measure its calorific value when buying their supplies, but in buying coal for the home there is no ready way of doing so. In the case of gas, however, gas companies are required by law to declare the calorific value of their gas (see page 219). Electricity is sold by the Board of Trade Unit which is usually called simply the unit of electricity. A unit of electricity supplies a definite amount of heat, 3,450 B.Th.U.s, and this quantity does not vary from one supply to another.

When comparing the actual costs of different sources of heat it must always be remembered that in practice all the heat cannot be usefully employed. For example, with a coal fire, often only about a fifth of the heat obtainable may be used in heating the room, the remainder being lost by incomplete combustion of the coal and through loss of heat up the chimney.

The quantity of heat given out by a source of heat may be found by using it to heat a definite weight of water. Suppose a certain source of heat raised the temperature of 200 grams of water from 12° C. to 42° C. in 5 minutes. Then:

$$\begin{aligned}\text{Heat given out in 5 minutes} &= 200 \times (42 - 12) \\ &= 6{,}000 \text{ calories.}\end{aligned}$$

This source of heat, therefore, gives out 1,200 calories in one minute. Two different sources can be compared, using this method, by finding the number of calories each gives out per minute.

Specific Heat.—An experiment will show that when the same steady flame is used it takes less time to raise the temperature of a weight of a liquid such as turpentine than it does to heat an equal weight of water through the same range of temperature. It follows that turpentine requires a less quantity of heat than the same weight of water does to raise the temperature to the same extent. The ratio of the quantity of heat required by the turpentine to that required by the water is called the *specific heat* of the turpentine.

Thus when the water requires ten minutes' heating it is found that the turpentine requires only four minutes, and hence only needs four-tenths of the heat required by the water. Hence its specific heat is 0·4.

> The specific heat of a substance is the quantity of heat required to raise the temperature of any weight of the substance divided by the quantity needed to raise the same weight of water through the same number of degrees.

It has been mentioned that

The quantity of heat taken in or given out by water
= (weight) × (change in temperature)

and it follows from the definition of specific heat that

The quantity of heat taken in or given out by a substance
= (weight) × (change in temperature) × (specific heat).

When hot and cold water are mixed they come to a common temperature and the quantity of heat which is lost by the hot water is gained by the cold water. The principle : Heat lost = Heat gained is used to find the specific heat of a substance. Thus, in an experiment it is found that when 100 grams of water at 48° C. are poured into 200 grams of methylated spirits at 15° C. the temperature after stirring is 30° C. If the specific heat is denoted by S then :

$$\begin{aligned} \text{Heat gained by spirits} &= 200 \times (30 - 15) \times S \text{ calories} \\ &= 3{,}000\ S \text{ calories} \\ \text{Heat lost by water} &= 100\ (48 - 30) \text{ calories} \\ &= 1{,}800 \text{ calories} \\ \text{Therefore, } 3{,}000\ S &= 1{,}800 \\ \text{and}\qquad S &= 0{\cdot}6. \end{aligned}$$

Hence, the specific heat of methylated spirits is 0·6.

The specific heat of a solid may be similarly found by pouring warm water on to a piece of the solid contained in a vessel (a calorimeter).

Heat Capacity.—In heating water it is obvious that some of the heat goes in raising the temperature of the vessel containing it. Actually the heat taken in by the vessel is much smaller than might be expected simply from its weight because of the small specific heat of the material from which the vessel is made. While 400 calories are required to heat 400 grams of water through a temperature rise of 1° C., a vessel of copper, (specific heat 0·1), which would contain it and which weighs say, 60 grams, would need $0{\cdot}1 \times 60$, or 6 calories, a comparatively small amount.

The heat capacity of a body is the amount of heat needed to raise its temperature through one degree, and that of a quantity of water is usually high compared with the same weight of other substances. It is, however, sometimes important to remember that when equal bulks or volumes are compared the heat capacity of water is not so marked since the density of water is small compared with solid materials.

Change of State.—Water normally boils at 100° C. and no matter how strongly it is heated its temperature will not rise beyond this even when large quantities of heat are obviously being supplied to it. The additional heat is used to change the water to steam. Similarly ice can be heated, but its temperature remains at 0° C. until all the ice has melted, the heat put into it being used to melt the

ice. Heat is required to change a solid into a liquid and a liquid into a gas, and the following experiment enables an approximate calculation to be made of the amount of heat required.

Small pieces of ice are placed in a metal can, along with a thermometer, and heated slowly over a bunsen-burner which is burning with a steady flame. The time from the commencement of heating until all the ice has melted is recorded (all the ice has melted when the temperature rises from 0° C.). The water so obtained is heated over the same flame and the time taken in raising its temperature from 0° C. to 100° C. is recorded. All the water is then boiled completely away and the time required for this is noted. Suppose these times are 4, 5, and 27 minutes respectively. For each gram of liquid water at 0° C. it will take 100 calories to raise its temperature to 100° C. This takes 5 minutes, and since a steady flame is used, the bunsen is supplying 20 calories of heat per minute to each gram of water. In 4 minutes the heat melted all the ice and 80 calories were given in this time to each gram of ice melted. Similarly in 27 minutes $27 \times 20 = 540$ calories were supplied to each gram of boiling water and turned it into steam. The heat required to change the state of a substance is known as the latent heat. Thus:

The latent heat of fusion of ice is 80 calories; this is the amount of heat required to change 1 gram of ice at 0° C. into water at 0° C.

The latent heat of vaporization of water is 536 calories; this is the amount of heat required to change 1 gram of water at 100° C. into steam at 100° C.

Maximum Density of Water.—Careful experiments show that the volume of a given weight of water gradually decreases as the water is cooled until a temperature of 4° C. is reached. Then, curiously enough, the volume of water increases as the temperature is lowered to 0° C. Thus water has its maximum density at 4° C. The effect of this peculiar behaviour of water is seen when a deep pond freezes. The surface water is the first part to be cooled, and the warmer water beneath rises to the top while the colder water flows to the bottom (see convection currents, page 89). This continues until the temperature at the bottom of the pond is 4° C. Then although the surface water becomes colder it does not sink because it is lighter (less dense) than the water beneath it at 4° C., and in time the water at the top freezes at 0° C. It expands on doing so and has no tendency to sink since ice is less dense than water

owing to the expansion. Ice and water are poor conductors of heat (page 88) and although there is ice at the surface there is not a great loss of heat by the water at the bottom of the deep pond. This water does not freeze but remains at about 4° C. Fish, plants and other pond life can live in the water at the bottom of the pond and are not frozen in a mass of ice as they would be in many cases if water at 0° C. had the greatest density, and if the density of ice were greater than that of water; for then as soon as ice was formed it would sink and freezing would take place from the bottom upwards.

Regelation.—The melting-point of ice is affected by pressure and is only 0° C. at atmospheric pressure. This fact can be demonstrated by hanging a weight at each end of a copper wire and then placing the wire across a block of ice (Fig. 71). Ice melts when subjected to a greater pressure than atmospheric, but as soon as the pressure is released it freezes again. The pressure underneath the wire is greater than atmospheric, so the ice melts and the wire passes through the water which is formed. But as soon as the wire has passed through, the pressure becomes atmospheric again and the water freezes. So finally a solid block of ice is left although the wire has passed through the ice.

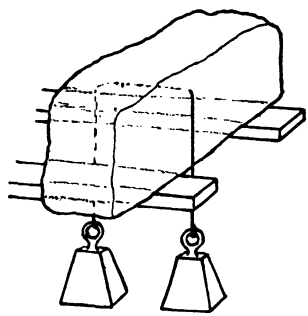


FIG. 71

When a snowball is made the snow is pressed closely together. This increase of pressure causes some of the snow to melt, but as soon as the pressure is removed the water freezes again leaving a frozen mass the shape of a ball. In a similar way the ice of a glacier when rounding a bend is pressed closely against its side. Some of the ice melts and the water so formed freezes when out of the region of pressure. Hence the glacier takes the shape of the bends and curves of the valley down which it flows, even though it is a solid river.

Evaporation.—Roads soon become dry after a summer's rain for the heat of the sun causes the water to evaporate and the vapour rises into the air. This process is known as evaporation and is taking place continually at the surfaces of lakes, ponds, rivers and seas. This water vapour sooner or later returns to the earth as rain.

The water vapour mixes intimately with the air and if sufficient of it is present the air becomes saturated and can hold no more.

Air which is capable of taking in much additional water vapour is said to be dry; if it is not so capable it is said to be moist or humid. The amount of water vapour required to saturate the air depends on the temperature, the greater the temperature the greater the amount the air can hold. Hence humidity depends not only on the quantity of water vapour actually present, but also on the amount the air is capable of holding. In winter, for instance, the cold air is often more humid than the air in summer, although there may then be actually less water vapour in the air since the air in summer, being hotter, can hold more of it.

Wet clothes dry quickly out of doors on a warm, dry, windy day, particularly when they are spread out to expose as great a surface as possible. Other conditions being the same the tendency for water to change into vapour is greater the higher the temperature and so evaporation is quicker on a warm than on a cold day. The drier the air the more water vapour it can hold, and on a windy day the vapour is blown away as it is produced, so that the air in close proximity to the clothes does not become saturated and evaporation proceeds at a quicker rate.

The humidity of the air affects all of us; we are continually losing moisture through the pores of our skin by evaporation. This is an important process and if impeded or hastened we suffer discomfort (page 310). Humidity is also an important factor in certain industries, e.g. cotton spinning is best done in a damp atmosphere.

Cooling by Evaporation.—Heat is used in changing a liquid to a vapour (page 84), so that when evaporation takes place, if this heat is not supplied to it externally it has to be taken from the liquid itself. Thus when a liquid undergoes evaporation its temperature is lowered. The cooling effect can be illustrated when ether, a highly volatile liquid, is placed on the watch glass underneath which are a few drops of water. Air is blown on to the ether by a bellows and some of the liquid evaporates. Soon the water beneath the glass is a mass of ice. There are many instances where this cooling effect is of use. In hot countries water is kept cool by storing it in skins. The skin is porous so that the outside is always moist. In warm weather butter is often kept under a cover of unglazed earthenware containing water which soaks through to the outside. Moistened muslin is also similarly used. In such cases the evaporation of water keeps the temperature below that of the surrounding air. Chills which follow from keeping on wet clothes are due to the water evaporating and so making the body cold. A human being

perspires and the moisture evaporates; this causes a lowering of the temperature, which is often most desirable in hot weather (page 310). Liquid ammonia (or liquid sulphur dioxide) is used in many refrigerators and is allowed to evaporate so that the temperature is reduced (page 199).

Boiling-point of Water.—When water is boiling bubbles of vapour are escaping freely into the atmosphere; these bubbles are formed in every part of the liquid, not only at the surface. The steam pushes away the air to make room for itself and so exerts a pressure equal or slightly greater than atmospheric pressure. Indeed, the pressure of the air above the surface of the water determines the temperature at which the water boils; the higher the pressure the higher the boiling-point. Thus, at the top of a mountain, where the pressure is considerably less than at sea-level, water boils at a lower temperature than 100° C; so low is it that the water is not hot enough to scald tea properly or to cook an egg.

When a liquid is heated in a closed vessel the vapour particles accumulate above the surface and the pressure in the space above the liquid gradually increases. If the vapour is not allowed to escape an explosion might occur in time and, to prevent this, safety valves are fitted to steam-producing boilers. In many steam engines the free escape of steam is deliberately restricted to allow high pressures to be obtained but there is always a safety valve which is set to come into operation when a certain pressure is reached. At these higher pressures the water boils at a higher temperature than 100° C. There are on the market specially designed cooking vessels in which the escape of steam is restricted with the resultant increase in boiling-point. The higher the boiling-point the shorter the time needed to cook many foods, so there is a saving of fuel. Besides this saving is the other advantage that many foods improve by rapid cooking.

A consideration of the facts of latent heat indicates that once water is boiling the supply of heat can be reduced to that required to maintain the boiling-point temperature. To supply more heat is wasteful unless the object is to convert the water into steam and much gas is wasted by not lowering the flame of the gas-ring once water needed for cooking has been brought to the boil.

Boiling under Reduced Pressure.—An experiment to illustrate this is illustrated in Fig. 72. The water in the round-bottomed flask (half full) is boiled until the steam produced has driven out most of the air from the flask. The flask is then corked tightly and contains boiling water and steam, but practically no air.

It is then inverted and a damp cloth placed on it. This causes the steam to condense and so the pressure above the surface is low. The water continues to boil although it has been cooled to a temperature much below 100° C.

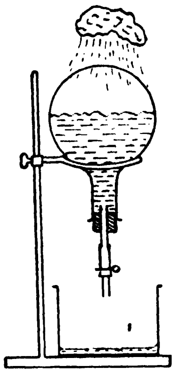


FIG. 72

TRANSMISSION OF HEAT

The sun is nearly 92,000,000 miles away from us, yet its heat warms the earth. What a tremendous distance the heat has to travel! All our artificial sources of heat are intended to supply heat to their surroundings and the heat from them has to travel some distance, however small. Heat only travels from one object to another when they differ in temperature, and it might travel in one of three ways, by conduction, convection or radiation.

Conduction.—When water is heated in a kettle over the fire the heat travels from the fire through the bottom of the kettle to the water. The handle of a poker soon becomes warm when the other end is put in a fire. In each case heat has travelled through the solid metal. The part near the source of heat obviously becomes heated first and the heat travels along the metal being "conducted" from particle to particle. Substances vary considerably in their power of conducting heat as can be shown by the apparatus in Fig. 73. This consists of a number of rods of different substances, copper, iron, aluminium, lead, etc., each of which is coated with wax. One end of each of them is fixed into a tank into which boiling water is poured. In a short time the wax melts at different heights, e.g. the wax on the lead has melted to a level near the tank while that on the copper has melted almost to the other end of the rod. The experiment gives some idea of the different conductivities of the various substances.

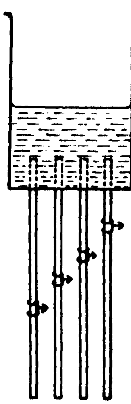


FIG. 73

Generally speaking, metals are good conductors of heat in comparison with solid non-metals, liquids are bad conductors and gases are very bad ones indeed. The poor conductivity of water can be shown by heating a test-tube of water at the top (Fig. 74); the lump of ice, wrapped in gauze to keep it at the bottom of the

tube, does not melt, practically no heat having been conducted through the water to it.

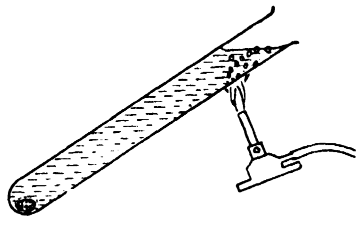


FIG. 74

Convection.—Since water is a poor conductor of heat the question arises why it so quickly becomes heated throughout when the heat is applied in the ordinary way at the bottom and sides of the vessel containing it. The manner in which the heat travels to do this can be illustrated by a simple experiment.

A small crystal of potassium permanganate is dropped to the bottom of a round-bottomed flask (Fig. 75), the flask is filled with water and is gently heated from below the crystal, using a small flame. The water round the crystal is coloured by the permanganate dissolved in it. Streaks of colour ascend to the top of the water and later descend down the side of the flask showing that the heated water rises to the surface and the cool water comes down to take its place. The reason for this is that the water nearest the source

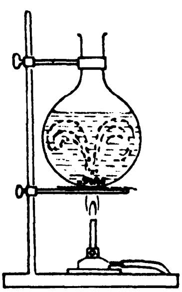


FIG. 75

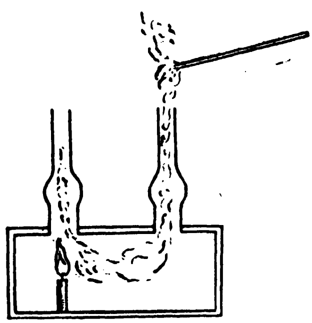


FIG. 76

of heat becomes hot and expands. It thus has a smaller density than the cold water above it, and rises. Convection currents are therefore due to the hot water rising and the colder water sinking to take its place. This colder water, in turn, becomes heated and in time all the water in the flask becomes warmer.

Convection currents are also set up in the air by heating it, since warm air rises while colder air falls in a manner similar to that described for water and for the same reason. This can be shown by using the apparatus in Fig. 76. The burning candle heats the

air immediately around it and the warm air rises up the chimney on the left while cold air descends down that on the right. The smouldering piece of paper produces much smoke which mixes intimately with the air and shows in which direction the air is travelling.

Radiation.—The heat given out by the sun has to travel 92,000,000 miles to reach us, and, except for a few miles near the earth, it has to travel through empty space. Actually the sun does not heat the air appreciably, either at high altitudes or near the earth. Heat travels from the sun by a method known as radiation (see page 120) and when the radiant heat falls upon an object it is absorbed and heats the object.

A coal fire passes heat into the room by radiation and, just as in the case of the sun, the air between the fire and the person or thing receiving the radiant heat is not necessarily heated. Thus we can shield ourselves from the fire's heat by holding say a piece of paper in front of us. The paper becomes hot but we ourselves do not, although surrounded by air which is evidently receiving but little heat from the fire. (In time the hot paper sets up convection currents. Actually the air of a room is warmed, to some extent, by convection currents set up by objects in the room which have become warmed by radiant heat.)

It does not need a very hot source like the fire or the sun to radiate heat. Any object warmer than its surroundings gives out heat by radiation and this accounts for the cooling of many things. Some surfaces radiate heat well, others do so badly, as shown by the following experiment. Two calorimeters, similar in every way except that one is highly polished and the other blackened, are filled with equal weights of hot water at the same temperature and left to stand in the same surroundings with a thermometer in each. The water in the blackened calorimeter loses heat more quickly than that in the polished one as will be indicated by a quicker fall in its temperature. Highly polished tea-pots (such as silver ones) radiate heat more slowly than a dull tea-pot does and so the tea in them remains hotter for a longer time.

Radiant heat is not absorbed until it falls on the surface of an object and the effect of having a dull, blackened surface compared with a bright polished one can be shown as follows. Two calorimeters (Fig. 77) are filled with equal weights of water and a thermometer is placed in each. Previously one has been highly polished, the other blackened. They are placed one at each side of a bunsen-

burner, each the same distance (about 6 inches) from it. The temperature of the water in each is recorded every minute and it will be seen that the water in the blackened calorimeter becomes

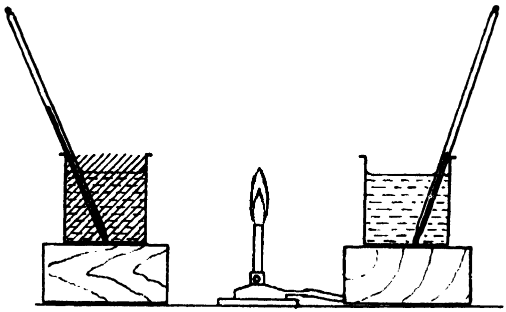


FIG. 77

warmer more quickly than that in the polished one. A dull blackened surface absorbs radiant heat better than a bright polished surface or than a white surface.

Heat Effects in Everyday Life.—The reason for using many of the common things in the home can be explained from a knowledge of the properties of heat. The hot-water bottle owes its use to the great heat capacity of water which is greater than that of any other substance. Thus a bottle full of hot water gives out a larger quantity of heat than it would were it filled with the same weight of any other liquid or solid at the same temperature.

Blankets and other woollen materials do not give out heat and so keep us warm ; this can be strikingly illustrated by wrapping a piece of ice in a blanket and putting it alongside another piece of ice exposed to the air. The latter melts first. Actually blankets keep us warm because they are bad conductors of heat and prevent the heat of the body from escaping. A blanket prevents the ice from melting because it prevents the heat from the air from being conducted to the ice. Substances which do this are known as insulators. New blankets are " teased," the fibres are pulled more or less upright so that the blanket has a fluffy appearance. The spaces between the threads are many and small, so reducing convection, and air is a bad conductor. Thus newly teased blankets are better insulators than old blankets which have had the fibrous nature of their surfaces more or less destroyed by many washings. The fur of an animal, and the feathers of a bird, besides being

of good insulating material (i.e. bad conducting), also have air in the spaces between the fibres and so keep the heat near the animal's surface. In a similar way mesh net or cellular underwear is a good insulator since air fills the pores.

White clothing does not absorb as much radiant heat from the sun as does black; hence its use in tropical countries and in England during the summer. Cotton is a better conductor than wool so that cotton clothes allow more of the body heat to escape than do woollen ones—a great advantage in hot weather.

Thermos flasks are used either to keep a liquid hot or to keep a substance, e.g. ice-cream, cold. If either a hot or a cold substance were left in the air they would in time attain the temperature of the air mainly owing to radiation of heat either from or to the contents. The inner glass vessel is the real thermos flask, the outer metal case being merely to protect it from breakage. The glass vessel, Fig. 78, has double walls and the space between them is a vacuum. Heat cannot pass by conduction or convection through this vacuum. It can pass through it, however, by radiation and so the glass surface is silvered. A silvered surface does not radiate much heat (page 90), neither does it absorb much. Hence the flask prevents the liquid from losing or gaining much heat.

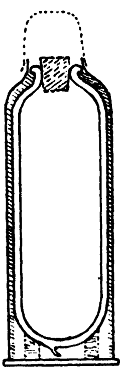


FIG. 78

It has been mentioned, page 84, that heat is required to change ice into water and use is made of this fact in making "cold drinks." Pieces of ice are put in drinks to make them cooler not only because the ice is at 0° C. but also because some of the ice melts and in doing so takes 80 calories of heat from the liquid for each gram of ice which melts.

Different substances conduct heat to a different extent; iron is a good conductor whereas wood is a bad one. This fact accounts for the iron feeling colder to the hand than the wood, even though both are at the same temperature (as could be shown by placing a thermometer on each of them). When either is touched it conducts heat away from the body, which is at a higher temperature. But iron being the better conductor conducts more heat away than the wood and owing to this greater loss of heat by the hand the iron feels colder. In a similar way a stone floor feels colder than a carpet, although both are at the same temperature. Stone is a

better conductor than cloth and so conducts more heat away from the bare foot than does the carpet. Hence it feels colder.

Miners need a light in the dark coal-mines, but in the presence of the inflammable gases which are present in mines (fire-damp, etc.), a naked light would be highly dangerous. The Davy lamp consists of a naked flame surrounded by a wire gauze (Fig. 79) which allows air to get inside. Gases do not explode until they are heated to a certain temperature which is known as the ignition temperature. The inflammable gases burn inside the lamp with a bluish flame but the heat produced is conducted away by the gauze and the temperature outside the lamp does not reach the ignition point. The blue flame also shows the presence of the gas. This is important as there is the danger when too much gas is burning in the lamp that the gauze may not conduct the heat away rapidly enough to prevent an explosion.

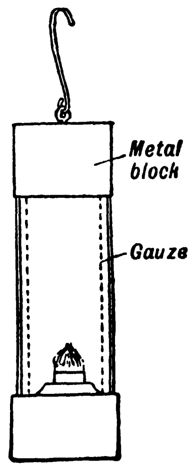


Fig. 79

One ill-effect of expansion results in the bursting of water-pipes during wintry weather. This is due to the fact that when a volume of water freezes it produces a greater volume of ice. That is, ice is less dense than water (and for this reason an iceberg floats). The powerful forces exerted as a result of this increase in volume can be demonstrated by completely filling a cast-iron bottle with water and then screwing the cap on tightly. When the bottle is placed in a freezing mixture ice is formed and the bottle bursts into pieces. Much the same thing happens in a water-pipe when the water inside freezes. But the burst is not usually noticed while the ice is inside because ice, being a solid, does not run out. As soon as a thaw sets in and the ice melts the water then formed runs out and gives a false impression that the pipe has burst during the thaw. Pipes in danger of being frozen should be kept warm by a suitable source of heat being placed near, or they may be "lagged," i.e. covered with some non-conducting material, such as straw.

Heat Effects in Nature.—A severe frost breaks up many rocks. The rain fills the cracks and crevices of the rocks and on being frozen it expands and the force of expansion often breaks the rocks apart.

The sea has a much greater heat capacity than land, for the

sun's rays penetrate deeply into the sea, so warming a much larger volume of material than in the case of land, which absorbs the heat at the surface, and the heat is slow to penetrate it. Another cause of the high capacity for heat of the sea as compared with the land, is the high specific heat of water compared with the material of the land. The sea acts as a kind of reservoir of heat. The land is consequently hotter than the sea in the daytime because it heats up more quickly and is colder at night because it loses its heat more rapidly. In winter, too, the sea is on an average warmer than the land while in summer it is cooler. This has its effect on

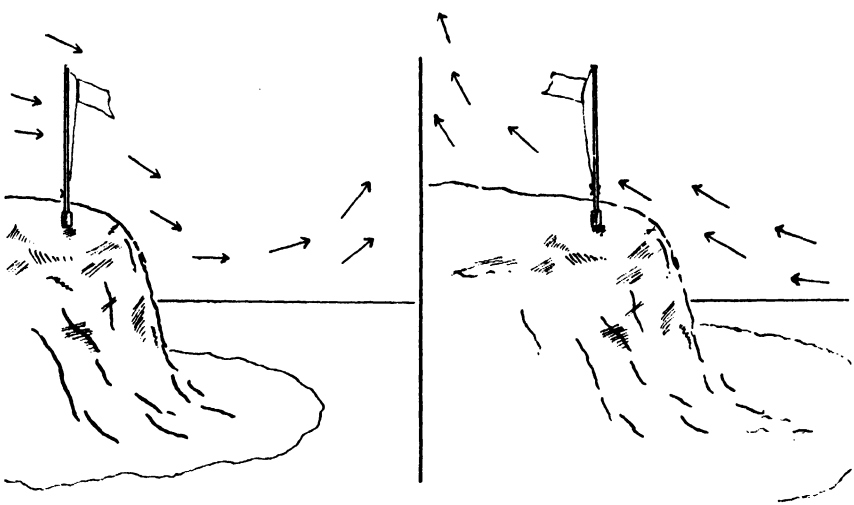


FIG. 80

climate, places close to the sea being usually warmer in winter than those further inland. Since the land by the sea is hotter than the sea during the day the air over the land becomes warmer than that over the sea and rises, cold air from the sea flowing inland to takes its place. There is thus a tendency by day for sea breezes, i.e. colder winds from the sea to the land (Fig. 80). At night the reverse conditions apply ; the sea is hotter and the breeze tends to blow from land to sea.

When air is saturated with water vapour, as it frequently is over the sea and over fenland, etc., a fall in temperature causes some of the water vapour to condense, forming mist. When the droplets of water are formed round particles of soot or dust, etc., fogs are pro-

duced. Fogs therefore occur usually in the neighbourhood of large towns where there is much soot and dust in the air.

The upper regions of the atmosphere are colder than the lower ones, so that as warm moist air rises it falls in temperature. Some of the water vapour it contains condenses and forms clouds, which consist of tiny droplets of water. They remain suspended and if the temperature near the clouds falls further (usually through the cloud being carried upwards by air currents), more moisture forms round the drops. They thus become bigger and heavier and so start to fall as rain, collecting smaller droplets on their way to the earth. Snow is formed instead of rain when the temperature of the air in the neighbourhood of the clouds is sufficiently low. Hail, on the other hand, is formed when drops of rain are first formed and are then carried by air currents into the colder upper regions, where they freeze and finally fall to the earth as hail.

Air containing insufficient water vapour to saturate it at a certain temperature may ultimately become saturated when it is cooled and further cooling results in condensation. (A familiar example is met with when ice-cream is placed in a glass vessel. The outside of the glass is usually wet with condensed water from the air.) On cold days condensed water forms on the inside of window-panes. The glass is cooled by the outside air and the air of the room on coming in contact with the glass becomes colder, and deposits some of its moisture on the cold surface of the glass.

The temperature at which moisture starts to be deposited from the air as it is cooled is called the Dew Point. The dew point may be found by the process of cooling water which is contained in a polished copper calorimeter by the addition of small pieces of ice. The temperature of the water is noted at which the polished surface becomes dull due to a film of moisture being formed on it. When the dew point is low compared with the air temperature it shows that the air is relatively dry. When the air is moist the two temperatures are more nearly the same.

Another method of judging the humidity of the air is by means of the Wet and Dry bulb thermometer readings. These are among the usual observations taken at meteorological stations. Two similar thermometers are used side by side, but several inches apart. The bulb of one is wrapped round with a material such as muslin, which is kept moist because its lower end is dipping into water and acts as a wick. The moisture evaporates from the covering and produces a cooling effect (page 86). This results in a cooling of the

bulb due to the heat being removed by the evaporation. The drier the air the greater is the evaporation and the lower the temperature registered by the wet bulb compared with the air temperature which is registered by the dry bulb thermometer. Hence the difference in the two temperatures is a measure of the humidity of the air and tables have been compiled to estimate the humidity from a given difference in temperature.

At night the earth and objects on it lose heat by radiation and may become much colder than the air. For instance, there may be ground frost at night without the air temperature being below the freezing-point. An object cooled by radiating heat in this way cools the air immediately surrounding it and moisture is deposited on the object in the form of dew. The formation of dew is helped by the air containing a reasonable amount of water vapour, but the main bulk of the air need not be saturated. The night must not be windy, otherwise the air is removed from the cold surface before it is sufficiently chilled to fall to the dew point. A clear or cloudless night assists in dew formation because it allows for free radiation. A surface needs to be a good radiator of heat and a poor conductor to give the fall in temperature necessary for dew to form well on it.

Hoar frost is formed instead of dew when the surface falls to the freezing-point of water, when the vapour condenses directly into the solid form.

CHAPTER XI

LIGHT

THERE are relatively very few real sources of light and most things are seen only when they are illuminated by light which falls upon them. This is apparent on going into a dark room, for nothing is seen because the things in the room are not illuminated. As soon as a light is introduced the things can be seen because light falls on them and is reflected from their surfaces.

It is not usually difficult to tell whether an object is a real source of light or is merely a reflector. For example, the red reflector of a cycle is invisible at night until the lights from a car shine on it. Then it shines as brightly, in many cases, as if it were a red lamp, but as soon as the lights from the car no longer shine on it the reflector becomes almost invisible again. Many of the new road signs become bright by reflected light, the part of the sign to be illuminated being made of glass cut in such a way as to reflect light which falls on it. Occasionally, however, it is not directly apparent whether the object is a real source of light or is made visible by reflection. The moon, for example, gives light to the earth by reflection. It is not a true source of light, for at times only a part of it is visible and that is the part illuminated by the light from the sun.

Substances differ widely in their property of reflecting the light which falls on them. White surfaces and mirror surfaces reflect most of it ; coloured and grey surfaces reflect only a part, while a dull black surface reflects practically none. Transparent substances like water and glass allow light to pass freely through them. They transmit the light. The light which falls on a surface and is not reflected or transmitted, is said to be absorbed and a black surface absorbs all the light falling on it. Opaque substances stop all the light falling on them and either reflect or absorb it.

Sources of Light.—A source of light gives out or emits light and the sun is our only important natural source of light, for the

earth receives only a little light from the stars. Artificial sources of light are many. Frequently they are flames and the light is given out by white-hot particles of matter (usually of carbon), which are present in the flame. Other sources are not flames but have metallic wires which are heated to white heat (as in the electric lamp), or else some material is heated also to white heat (as in the gas-mantle).

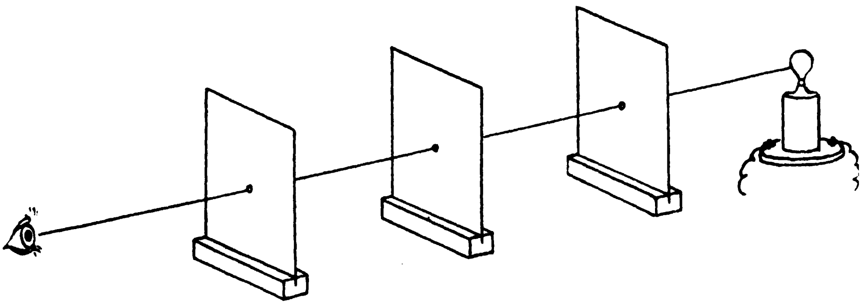


FIG. 81

Rectilinear Propagation of Light.—Light travels in straight lines as the experiment illustrated in Fig. 81 shows. A person looking through the hole can see the light only when the three holes make a straight line with each other. A straight line drawn in the direction in which the light travels is called a ray of light, while a number of rays make a beam of light. Diagrammatically a ray of light is shown by a straight line with an arrow in the direction in which the light travels. A source of light gives out light in all directions, and from all points on it. The eye sees a point in the source by the rays which enter it. These rays form a "pencil of light" diverging from the point to the eye as in Fig. 82.

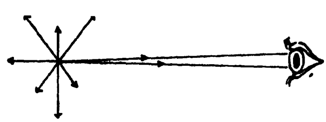


FIG. 82

Shadows.—The formation of shadows can be explained by using the fact that light travels in straight lines. A definitely defined shadow on a screen can be obtained only when a very small source of light, approximating to a point, is used. Such a source is shown in Fig. 83 (a suitable lamp is a small car-lamp bulb). The light falls on the large opaque circular object and a sharply defined shadow is shown on the screen. When a fairly large source of light is used, such as an opal electric lamp (Fig. 84), the shadow of the opaque

object lacks definition. There is a darker central portion which is known as the umbra on which no light from the source falls, with a partial shadow round it known as the penumbra which is only partially illuminated by the source. The light itself cannot be seen from any point within the umbra and is partially obscured if viewed from any point within the penumbra. Thus it cannot be seen by a person looking through a hole at C (in the umbra) and can only

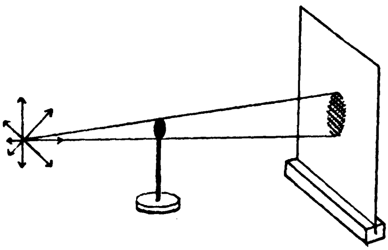


FIG. 83

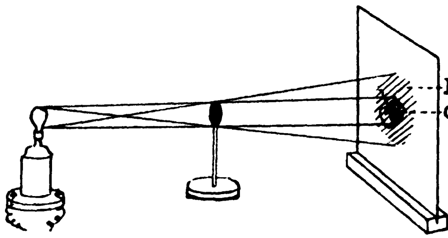


FIG. 84

be seen partially by looking through a hole at D (in the penumbra). The formation of these shadows is shown by the use of straight lines in the figure, where the rays indicated come from one edge or another of the source and fall on the screen at the edges of the shadows.

Eclipses.—An interesting natural phenomenon of shadow formation takes place during an eclipse of the moon. The moon

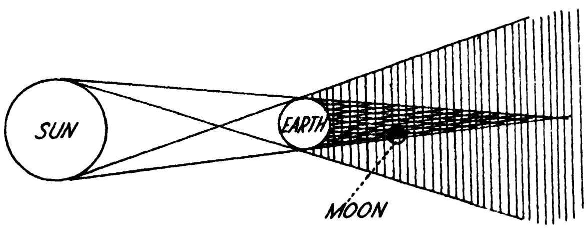


FIG. 85

travels round the earth and at times all or part of it is in the earth's shadow, (Fig. 85). When all the moon is in the umbra of the earth's shadow it is fully eclipsed, for since it receives no light from the sun it cannot reflect any and is invisible. A partial eclipse takes place when only part of it is in the umbra as shown in the figure.

When the moon passes between the sun and the earth, e.g. on

the opposite side to that shown in Fig. 85, the shadow of the moon is cast on the earth. People in the umbra of the shadow cannot see the sun and to them the sun is totally eclipsed.

Pin-hole Camera.—Because rays of light travel in straight lines it is possible to take photographs with a pin-hole camera, which has a tiny hole in its front instead of a lens. The principle of such a camera is shown in Fig. 86. An inverted image of the view in front of the pin-hole is obtained on the film at the back of the camera just as the image of a candle placed in front of the pin-hole can be got on a ground glass screen placed in the position of the film. The rays of light travel in straight lines from points on the candle and illuminate corresponding points on the screen as shown in the sketch, so that an inverted reproduction or image of the object is seen. The image may be obtained at any distance behind the hole and increases in size as the screen is moved back. In a pin-hole camera, when the hole is very small, little light passes through it and to get a photograph a long exposure of the film is necessary. On the other hand, if the hole is increased in size the image becomes blurred, because light from each point on the object diverging through the hole illuminates a small area of the film which cannot then be considered merely as a point. The inside of the camera is blackened to absorb any light which does not come directly from the objects photographed.

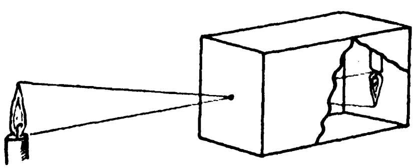


FIG. 86

Intensity of Illumination.—The ease with which most things can be seen depends to a great extent on the degree to which they are illuminated, i.e. the intensity of the light falling on them. The unit commonly used to measure this intensity is the " foot-candle," that is, the intensity of illumination obtained on a surface when a source of light of one candle-power is placed one foot from it. The " standard " candle from which the candle-power was fixed was one made of a particular kind of wax (spermacetic wax) in such a way that a definite weight of wax (120 grams) was burned per hour. An approximate idea of the intensity produced can be obtained by using an ordinary candle. Nowadays, however, electric lamps are used as standards of candle-power.

A small lamp twice as far away from one screen as from another has to illuminate an area on the farther screen four times as great

as that on the nearer one as Fig. 87 shows. With a small source of light the intensity of illumination varies not only with the candle-power of the source but also inversely as the square of the distance the light is from the object to be illuminated. Thus:

Intensity of Illumination $= \frac{C.P.}{d^2}$ foot-candles.

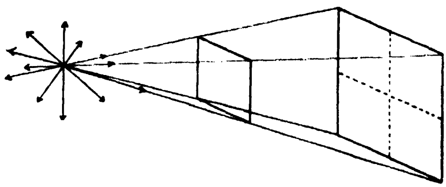


FIG. 87

Diffusion.—An object is visible in reflected light when the light coming from it is scattered from all parts of it in all directions, Fig. 88. This scattering of light is called diffusion. Surfaces like mirrors which reflect light in a regular way (Fig. 89), that is, without scattering it, are not themselves clearly seen, in fact a perfect mirror surface is invisible. This is also true of transparent substances like glass, which transmit light regularly and so are often invisible. Splashes of white paint, which scatter the light, are put on the windows of buildings in course of erection to show that they have been glazed. Also when the surface of a sheet of glass is

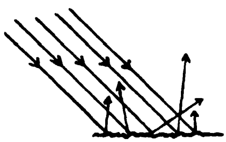


FIG. 88

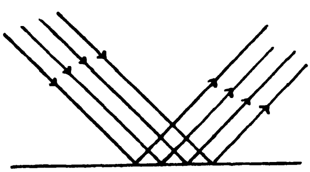


FIG. 89

roughened the light falling on it is scattered and the material is visible by reason of light diverging from all points on the roughened surface. Substances such as ground glass or opal glass which diffuse light in this way are called translucent substances, and act as sources of light when illuminated. The light passing through them no longer diverges from the original source of light which, for this reason, cannot be seen. This accounts for the use of opal electric lamps and translucent shades which, though they allow the light to go through them, prevent the filament from being visible and causing discomfort through its brilliance. (Actually a beam of light is invisible, but the path of a strong beam, such as that of

a searchlight, is made visible by the scattering of light from the surfaces of particles of matter in the air.)

Reflection of Light.—The image of an object seen in a plane mirror appears very like the object itself, but closer inspection reveals one difference. This is clearly noticeable when a clock is seen in a mirror, the left-hand side appears on the right hand and the figures on the clock face are the wrong way round. This phenomenon is called lateral inversion. Again, when ink-writing has been blotted, the markings on the blotting-paper differ from the original writing in being laterally inverted, but they appear normal on holding the blotting-paper in front of a mirror and looking at the image.

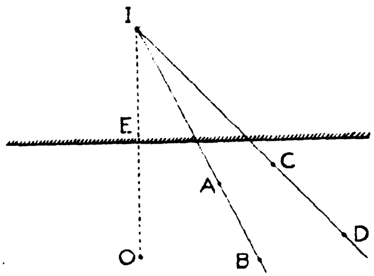


FIG. 90

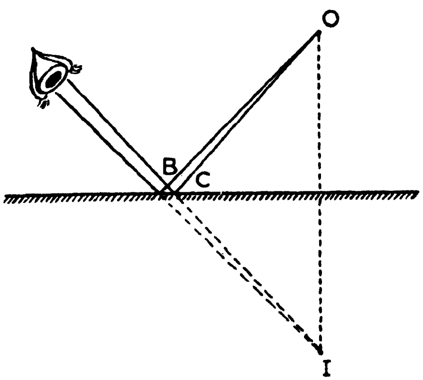


FIG. 91

The position of the image seen in a mirror of a small object such as a pin at O, Fig. 90, is found by placing two other pins, A and B, in front of the mirror so that these two pins appear in the same straight line as the image. A straight line is drawn through A and B and continued beyond the mirror. Two other pins, C and D, are placed so that they also appear in a straight line with the image and another straight line is drawn. The image is situated at the point of intersection of these two lines (point I). The line joining the image, I, and the object, O, is found to be bisected by the line of the mirror (i.e. IE = EO) and it is also perpendicular to it.

When an image is seen in a mirror, the rays of light only appear to diverge from it although they enter the eye just as if they really did so. How this happens can be seen from Fig. 91. The rays OC and OB on leaving the mirror enter the eye as if they came from the image I. Actually they come from the object, strike the mirror

and are reflected from it in a regular manner as shown by the continuous lines.

A few of the special terms used in connection with reflection must be known before this can be explained. A ray of light striking a mirror, or incident on it, is said to be an incident ray (Fig. 92). The ray leaving the mirror after reflection is a reflected ray. A line at right angles to the mirror at the point of reflection is called the normal. The angle between the incident ray and the normal where the ray strikes the mirror is its angle of incidence and the corresponding angle between the reflected ray and the normal is the angle of reflection. In mirror reflection the incident ray makes the same angle with the normal as does the reflected ray and both lie in the same plane.

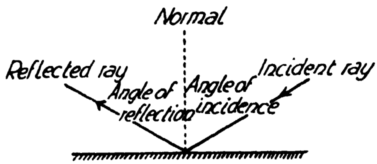


FIG. 92

From a knowledge of the laws of reflection it is possible to account for the effects of reflection in flat or plane mirrors. Thus the image

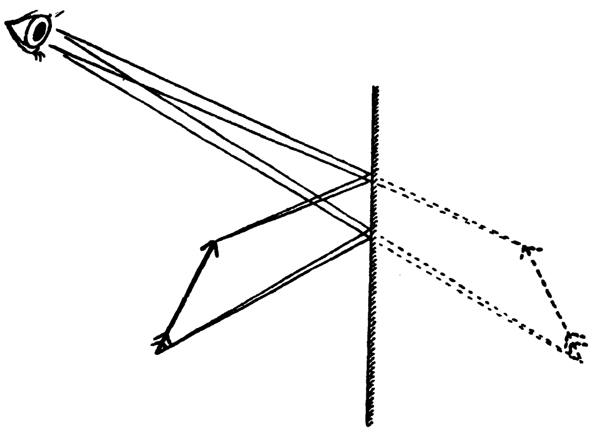


FIG. 93

of the object, indicated by an arrow, appears as shown in Fig. 93. It will be seen that the object and image are of the same size. The image is called a virtual image because light does not actually come from it but only appears to do so.

There are many applications of the use of a plane mirror besides its obvious use as a looking-glass. A plane mirror placed at an

angle of 45° to the direction of the incident ray turns the rays of light through a right angle. So that a plane mirror inclined at 45° and placed where two corridors meet at right angles to each other, enables a person to see others approaching round the corner. In the periscope two mirrors are used, one to change the direction of its rays through a right angle and another to bring the light back to its original direction, but along a different path. Periscopes of the kind shown in Fig. 94 were used during the War to see with safety over the parapets of the trenches and a rather more elaborate type is used on submarines.

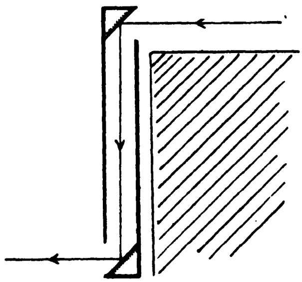


FIG. 94

Refraction.—Water appears to play strange tricks with our eyesight. When a stick is put into water slantwise it appears to be bent where it enters the water, yet when it is pulled out it is quite straight and unbent. The bottom of a large swimming-bath full of water seems nearer to us than it is, i.e. the depth of the water

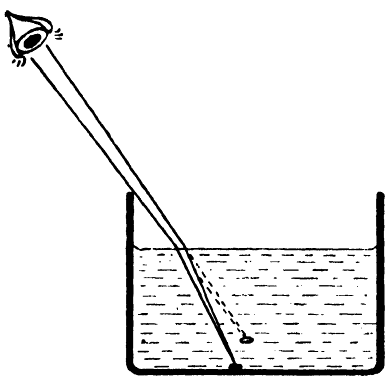


FIG. 95

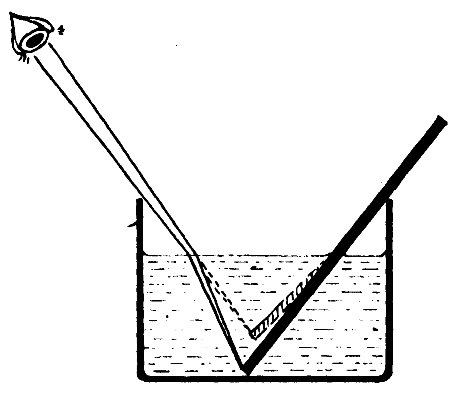


FIG. 96

is deceptive and it is possible to illustrate this by a simple experiment. A penny is put at the bottom of an empty enamel bowl and someone is asked to view it and then to stand a little farther off until it is just obscured by the edge of the bowl. When water is poured into the vessel the penny becomes visible although neither it nor the person has moved. An explanation is provided by the fact that

a ray of light travels from the coin through the water and on leaving is bent towards the surface of the water as shown by the continuous lines (Fig. 95). But the eye sees the object from where the rays appear to diverge and so the coin appears above the bottom of the dish where the two dotted lines meet. The apparent bending of the slanting stick can be explained similarly. The rays of light from each point of the submerged stick are bent towards the surface of the water on leaving it and the effect is as shown in Fig. 96.

The change of direction which takes place when light travels from water to air is called refraction. Refraction occurs whenever light passes from one medium to another, e.g. from glass to air, glass to

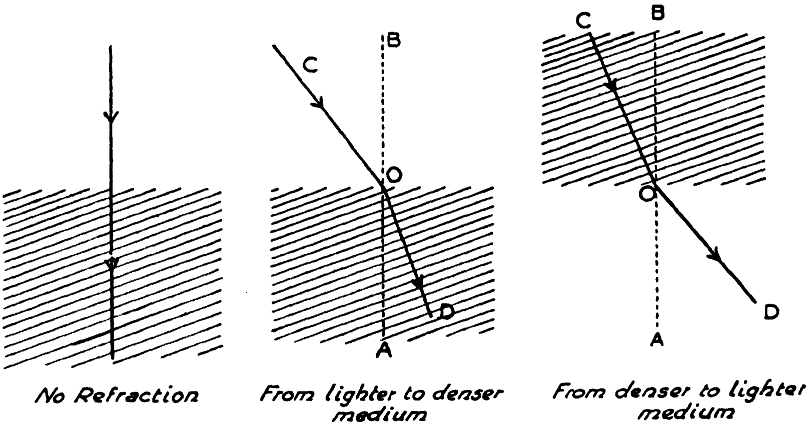


FIG. 97

water, air to water, air to glass, etc. ; but it only occurs when the rays of light strike the surface obliquely and then enter the new medium. There is no refraction when light strikes a new surface at right angles—the light continues in the same straight line as before. When the ray passes from a lighter into a denser medium, i.e. from air into water, the angle AOD which the refracted ray (Fig. 97) makes with the normal, is smaller than the angle BOC made with the normal by the incident ray. Conversely when the ray passes from a denser to a lighter medium (from water into air) the angle of refraction AOD is greater than the angle of incidence COB. Both angles are, however, always in the same plane.

Most of the effects of refraction are best illustrated by the use of glass in the form of prisms and lenses, the surfaces of which have

been specially prepared, that is, ground and polished, or optically worked. They must have true surfaces, i.e. prisms must have perfectly plane surfaces while the surfaces of lenses usually are parts of a sphere.

The path of a ray through a block of glass is shown in Fig. 98. When a pin is at O near the edge of a rectangular block of glass, it appears to be at the point I when viewed from the opposite side

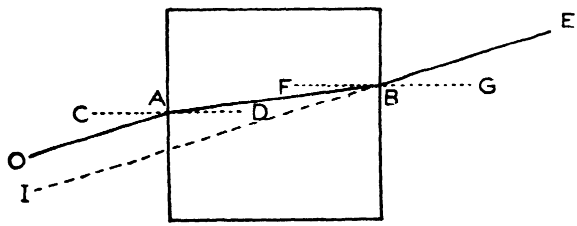


FIG. 98

of the prism at E. The incident ray strikes the glass at A and is bent towards the normal, the angle OAC being greater than DAB. On emerging from the glass to the air at B, the ray is bent away from the normal (ABF < GBE). The emergent ray BE is travelling parallel to the incident ray (OA) and the image appears at I.

Passage of Ray through a Prism.—The incident ray OA, Fig. 99, is bent towards the normal CD so that angle OAC is greater than DAB but on emerging at B is bent away from the normal so that angle ABF < GBE. The angle between the incident and emergent rays is called the angle of deviation. When a number of experiments are made varying the size of the angles of incidence (OAC) it is found that the

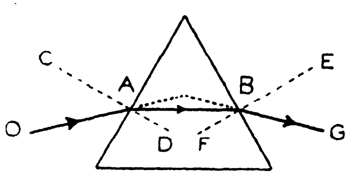


FIG. 99

angle of deviation is least when the incident and emergent rays make equal angles with the normal, that is when the ray passes symmetrically through the prism, AB being parallel with the base, then the deviation of the rays is the least.

Total Reflection.—The angle of refraction is always greater than the angle of incidence when light passes from a denser to a lighter medium. Consequently there is an angle of incidence at which the angle of refraction becomes equal to a right angle and refraction into the less dense medium becomes impossible. This

particular angle of incidence, which is called the critical angle, is about 42° in the case of a ray in glass striking a surface separating it from the air. At angles greater than this there is total reflection at the surface of separation and the prism acts like a mirror surface. Thus a right-angled prism can be used in place of a mirror to turn a beam of light through 90° as shown in Fig. 100; the incident ray strikes the sloping side at an angle of 45°. Since this angle is greater than 42° there is total reflection and the ray is reflected at right angles to its previous direction.

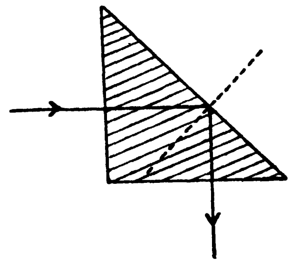


FIG. 100

Converging or Convex Lenses.—An ordinary magnifying-glass or burning-glass is called a converging lens because it brings a beam of light passing through it to a focus. The sun's rays are brought to a hot point when passed through a burning-glass and this spot is known as the focus (from a Greek word meaning "fire-place". Burning-glasses were known to the ancient Greeks and sold as curiosities.) The glass is thicker at the centre of a convex lens than at the edges and one surface at least is rounded or convex. The rays passing through the lens are deviated towards the thicker part of the lens, just as rays are bent towards the thicker part of a triangular prism, and all meet at a point which is called the focus.

The line which passes symmetrically through a lens is called the axis. When the lens is held at right angles to a parallel beam of light such as that coming from the sun the focus is on the axis and the distance of this focus from the centre of the lens is called the focal length of the lens.

The focal length of a common lens may be found by focusing sunlight or the light from a distant lamp on to a screen. The more round the surfaces, i.e. the thicker the lens in relation to its diameter, the shorter is the focal length and the greater is the power of the lens or its ability to converge the rays in a beam of light.

It has been seen that a parallel beam of light is converged to a focus on passing through the lens. This is illustrated in Fig. 101, A. Conversely when a small source of light is placed at the focus a parallel beam emerges from the other side (Fig. 101, B). A flash-lamp bulb, which can be regarded as a small source of light, is placed at the focus of a bull's eye (convex) lens. The light passing through it is concentrated in an almost parallel beam and the intensity of

illumination provided in the path of the beam is much greater than it would be without the lens. There are two such principal foci to a convex lens, one on each side of the lens and each at the same distance from it.

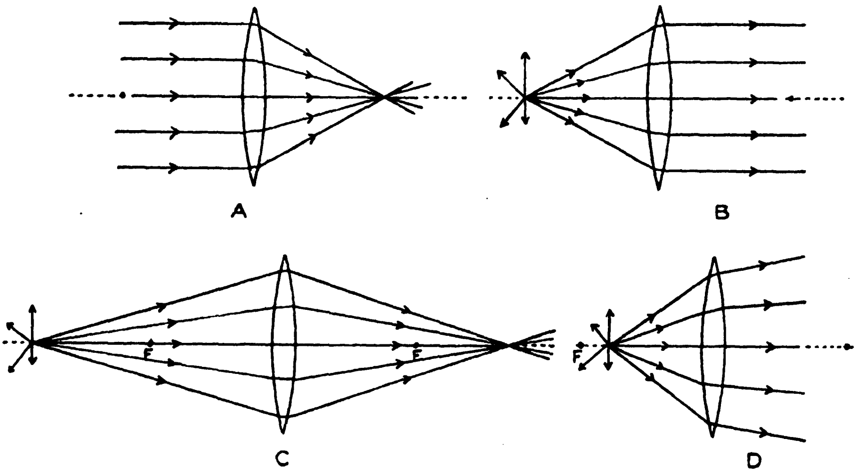


FIG. 101

In figure 101, A, B, C, and D together show the effect of the lens in converging the rays. In A the incident beam consists of parallel rays and the rays are brought to the principal focus ; in C the rays are slightly divergent and brought to a focus farther from the lens

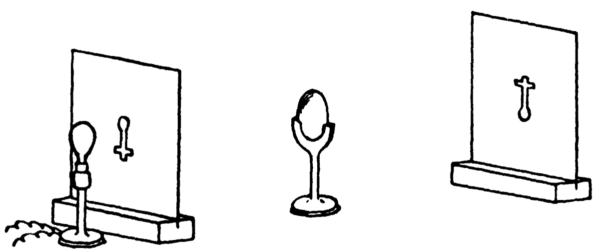


FIG. 102

than the principal focus. In B rays are shown diverging from the principal focus and are rendered parallel, while in D the rays are more divergent than before and the converging action of the lens is not sufficient to bring the rays parallel to each other although the degree of divergence is decreased.

Converging lenses can be used to obtain images on screens. The rays of light coming from any point on an object are converged by the lens to a corresponding point on the other side as shown in Fig. 101, C, for a point on the axis of the lens. Thus a real inverted image of the cross illuminated by a lamp (Fig. 102) is produced by the lens as shown. Convex lenses are used in many different optical

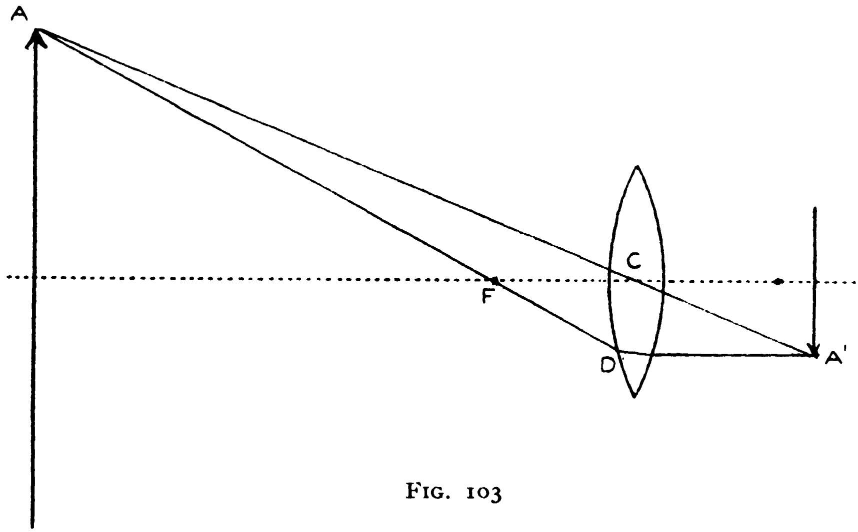


FIG. 103

instruments and the exact size and position of the image can be obtained by geometrical construction using the following facts:

(1) A ray of light parallel to the axis on emerging from the lens passes through the principal focus on the other side of the lens.

(2) A ray of light after first passing through the principal focus emerges from the other side of the lens in a line parallel to the axis.

(3) A ray of light passing through the centre of the lens is not deviated but continues in the same straight line, e.g. ray ACA′ in Fig. 103.

The most important applications of convex lenses in the formation of images are based on the following three types:

Type I.—When the object is at a considerable distance from the lens, as in the camera or telescope (Fig. 103). The point A is connected to C and the line continued. A is also joined to F

and continued until it meets the lens at D. A line is then drawn parallel to the principal axis until it intersects the other line.

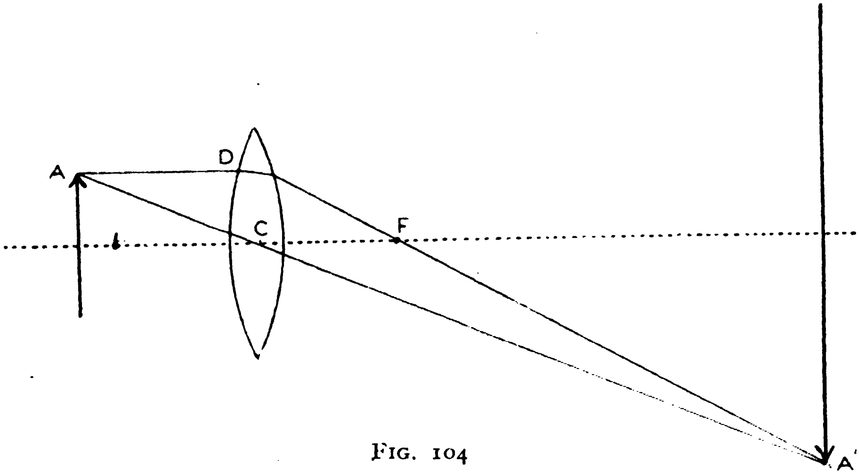


FIG. 104

This gives the point A′ which is the position of the image of A. The image obtained is diminished, inverted and real—real because it can be caught on a screen.

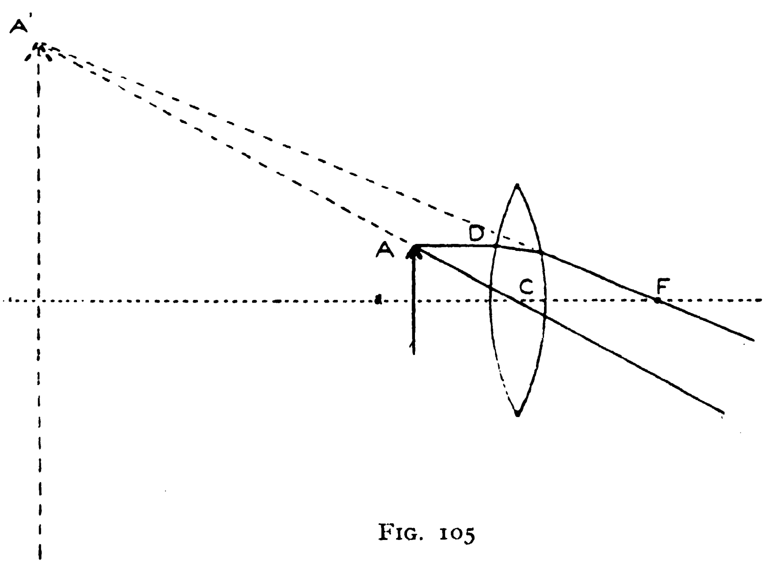


FIG. 105

Type II.—When the object is just beyond the principal focus, as in a projecting lantern or compound microscope (Fig. 104).

AD is drawn parallel to the principal axis and the point D when it meets the lens is connected to point F and the line continued. A is joined to C and the line continued until it intersects the other line at point A′. The image is enlarged, inverted and real.

Type III.—When the object is nearer the lens than the principal focus, e.g. a magnifying-glass (Fig. 105).

A line joining A and C is drawn and continued beyond A. The line AD is drawn parallel to the principal axis and a line joining D and F is drawn and continued beyond D until it intersects the other line at point A′. The image is enlarged, upright and virtual (it is said to be virtual since it cannot be caught on a screen). The eye sees it when the object is viewed from the other side of the lens, but the image is on the same side of the lens as the object.

Diverging or Concave Lenses.—A diverging or concave lens differs from a converging or convex lens in that it is thinner in the

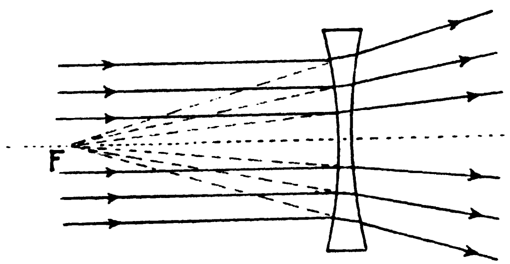


FIG. 106

middle than at the edges. When rays of light pass through the lens they are refracted, being bent towards the thicker part of the lens, i.e. to the outer edges and not towards the principal axis as they are when a converging lens is used. Hence, when parallel rays of light are passed through, they are spread as shown in Fig. 106. Geometrically, the focus of the lens can be found by producing the rays backwards, when they meet at F (principal focus). To anyone looking through the lens from the opposite side to F at a distant object, the rays appear to diverge from F where the image is seen.

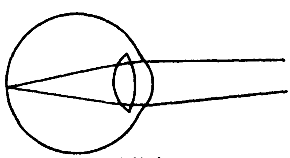
The Camera.—The ordinary camera has a convex lens which

produces an image of the object photographed on the film or plate. The image of a distant object is formed inside the camera at a distance from the lens equal to the focal length. This focal length of the lens therefore determines the position of the film. The image is inverted and obviously diminished. For nearer objects the image is formed at a greater distance from the lens than the focal length (as shown in Fig. 103) so that a focusing arrangement is usually employed. This adjustment is carried out by expanding or contracting the bellows which moves the lens away from or nearer to the film.

Only the middle part of the lens is generally used and its size can be adjusted by a diaphragm or stop. On a bright day either the hole or aperture used must be smaller than it is on a dull day or else the time of exposure must be smaller, since the effect on the film or plate depends on the total quantity of light entering the camera during the period of exposure. (When the stop is very small the conditions become comparable to those in a pin-hole camera, where the image is clearly defined without any focusing.) The timing of exposure is arranged by means of the shutter mechanism which is released when the photograph is taken, so opening the shutter for the required period, e.g. 1/25th second. The inside of the camera is blackened to absorb the stray light not coming from the object photographed.

The view-finder is generally a mirror set at 45° to the axis of the lens, so that by looking downwards into it the image can be seen as the view appears in the photograph. Sometimes a prism giving total reflection is used in place of the mirror.

The Human Eye and Spectacles.—A fuller description of the eye is given on page 333, and for the present purpose the lens and its muscles and the retina only will be considered. The lens of the eye, Fig. 107, is convex and forms an image on the retina. Essentially the eye is like the camera and the retina corresponds to the film. The image is diminished, inverted and real (Type I) as is shown in Fig. 103. Just as a focusing arrangement must be used to get a clear image in the camera, so also must the eye be capable of focusing. This it does by use of the muscles attached to the eye-lens (page 333.) When near objects are being seen the focal length of the lens is shortened so that the rays of light are converged more than when



Normal Vision

FIG. 107

distant objects are being seen. In a person with normal sight the image is always formed on the retina owing to this "accommodating action" of the eye. A short-sighted person sees objects blurred, particularly those at a distance, because the image is formed in front of the retina, Fig. 108. The defective eye makes the rays of light entering it too convergent for the image to be correctly focused. A diverging or concave spectacle lens corrects for this by increasing the divergence of the rays before they enter the eye. This effect is shown exaggerated in Fig. 108. Long-sighted persons, on the other hand, see objects blurred, particularly those near to the eye, because the image is formed behind the retina. The eye lens does not make the rays entering the eye sufficiently convergent for the image to be correctly focused. A converging or convex lens corrects for this by decreasing the divergence of the rays before they enter the eye. This effect is shown exaggerated in Fig. 109.

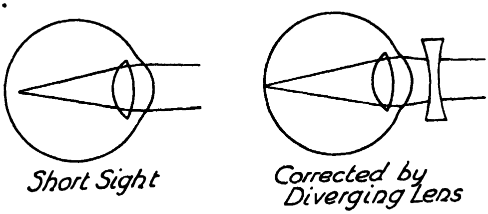


FIG. 108

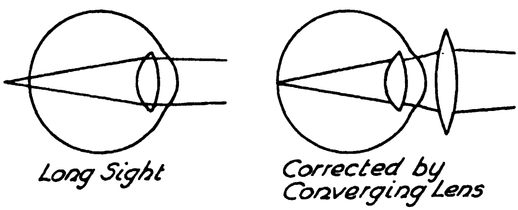


FIG. 109

Persistence of Vision.—The impression produced by an image on the retina persists for some short time after the light producing it ceases to enter the eye. One consequence of this is the illusion of movement produced by a cinematograph. The pictures, which follow each other at the rate of 16 a second, are not seen separately with gaps between them, but each impression persists until the next image is formed.

The Projecting Lantern.—A film or slide illuminated from behind is placed at a distance from a convex lens only slightly greater than the focal length of the lens. The image produced on a distant screen is magnified, inverted and real (Type II, Fig. 104), and it is necessary to put in the film or slide the wrong side up. The light which illuminates the slide passes through it, but before doing so it is converged by a convex lens called the condenser, which

is placed in front of the source of light used. The source is either an electric arc or an electric lamp with a small filament.

The Magnifying-glass.—The object is nearer the lens than the focus and is viewed from the opposite side of the lens. Thus an enlarged, upright and virtual image is obtained (Type III, Fig. 105).

The Microscope (Fig. 110).—The two essential lenses are the eye-piece and the objective which are placed at opposite ends of

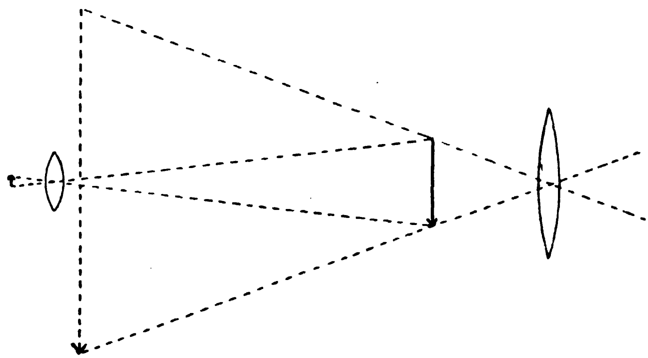


FIG. 110

the tube. The objective is a convex lens of very small focal length, e.g. $\frac{1}{12}$ in., and the object is placed near to it, though the distance is still more than the focal length away owing to the very small focal length of the lens. Hence the objective gives an image as in Type II, Fig. 104, and this image is formed inside the tube. The eye-piece is a convex lens and magnifies the image, as does the lens in Type III, Fig. 105. The first image is focused by moving the objective.

The Astronomical Telescope (Fig. 111).—The object glass is a convex lens, and since the object viewed is always at a great distance

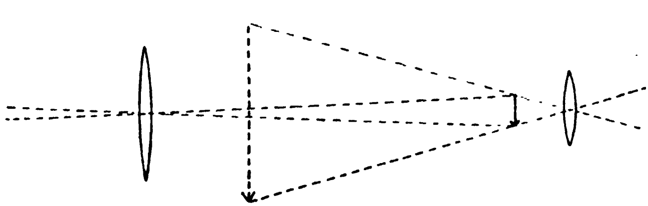


FIG. 111

from it, the lens acts as in Type I, Fig. 103, producing within the tube a diminished, inverted and real image. This image is viewed

through the eye-piece (Type III, Fig. 105) and an enlarged upright and virtual image of it is produced.

Concave and Convex Mirrors.—A convex lens, such as the bull's-eye lens of a flash-lamp (page 107), gives a concentrated beam of light from a small source placed at the focus. A concave mirror is frequently used for the same purpose, and when a small source of light is placed at a certain point in front of such a mirror the rays after reflection form a parallel beam if the mirror is a parabolic one. This point is called the focus. Parabolic mirrors are used in motor-car head-lamps and in searchlights.

A spherical concave mirror, Fig. 112, produces almost the same effect for rays with a small angle of incidence. In all such mirrors the normal at any point A is the line from A through the centre of the sphere of which the mirror forms a part. This centre, C, is called the centre of curvature and the focus, F, is midway between the mirror and the point C.

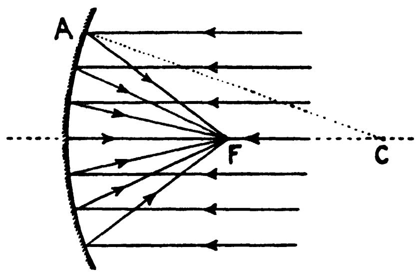


FIG. 112

Conversely, the rays of a parallel beam of light which strike the mirror are brought together at the focus. When the rays come from a distant object a real image is obtained at the focus, which may be compared with the real image obtained at the focus of a convex lens. A concave mirror is used in large telescopes in place of the object glass, for such a mirror can be much larger than the corresponding lens, e.g. a large reflecting telescope may have a mirror with a diameter of 100 inches.

A concave mirror is used in place of a plane mirror because it gives a magnified image of an object seen in it instead of an image of the same size as the object. Thus a shaving-mirror gives a magnified image of the face. To give such an image the object must be between the mirror and the focus. The size and position of the image formed in a concave mirror may be obtained, as in Fig. 113, by a geometrical construction using the following facts:

1. A ray, AD, which is parallel to the axis, on reflection from the mirror passes through the focus, line DF.

2. A ray, AE, which is normal to the mirror, namely one in line with the centre of curvature, is reflected along its initial path EAC.

3. The lines FD and CAE produced backwards intersect at the point A′, which is the position of the image of A.

It is seen that the image is erect, magnified and virtual, for an object placed between the mirror and the focus.

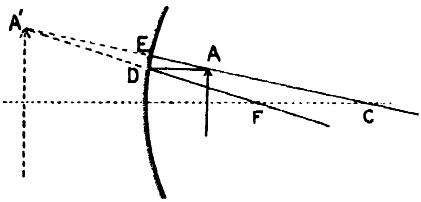


FIG. 113

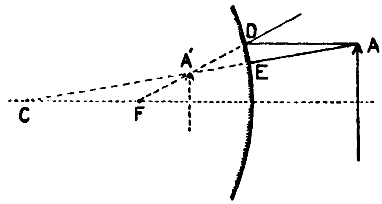


FIG. 114

A mirror shaped as in Fig. 114 is called a convex mirror, and the geometrical construction used to obtain the size and place of the image follows the same general rules. Such a mirror is used as a driving-mirror on a car since it gives the driver a wide field of view of the road behind him. The image formed in a convex mirror is erect, diminished and virtual, and such an image is formed when the object is at any distance from the mirror.

CHAPTER XII

RADIATION

Colour.

SIR ISAAC NEWTON (1642–1727) showed that when a beam of sunlight enters a darkened room through a narrow slit and then passes through a triangular glass prism (Fig. 115), a coloured band called a spectrum is formed on a screen placed in the path of the light. The colours are those of the rainbow and are in the same order, i.e., red, orange, yellow, green, blue, indigo, violet. The glass prism is made of plain glass and so cannot have produced the colours. Obviously these colours must have existed in the white light before the beam passed through the glass. Yet they were not

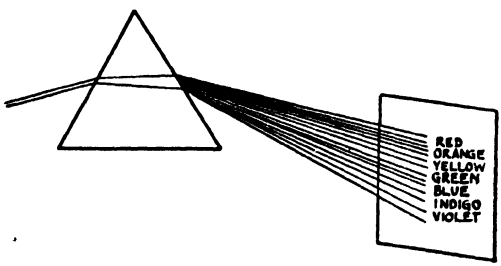


FIG. 115

evident before for they were all merged together and produced a white light.

The merging of colours can be shown by dividing the area of a circular white card into seven segments. The first is painted red, the next orange and so on to violet. If this card is rotated quickly it appears white despite its various colours. Actually white light is composed of rays producing all these colours, but the eye cannot distinguish them separately. A beam of white light consists of a number of rays and these are refracted or bent when the beam is passed through a glass prism. The rays responsible for the different colours of light are not bent to the same extent and are

separated on the screen, giving the colour effect known as the spectrum. This separation of the rays by refraction is called dispersion. Rainbows are produced by the dispersion of the sun's rays by drops of rain.

A small source of white light, such as an electric lamp, can be used to produce a spectrum. The rays of each of the different colours are brought to a focus on the screen by placing a convex lens between the source of light and the prism. Unless the lens is used the colours on the screen will overlap.

It was mentioned, page 97, that most objects are seen by reflected light. White objects reflect the coloured rays in the proportion in which they are contained in white light and so the objects appear white. A black object, however, absorbs the rays of all the colours, and since none of them are reflected the object appears black. A coloured object absorbs some of the rays and reflects others. Thus an object may appear red when white light shines on it because the colouring matter absorbs all the other rays of light except the red ones which are reflected. But more often an object appears coloured because a mixture of rays is reflected from it, such as when it reflects green and red rays and appears yellow. For instance, a rotated disc appears yellow when painted in red and green sections, provided the sizes of the sections are suitably chosen. The surface of the rotating disc is indistinguishable from that of a disc painted yellow. Actually all colours may be obtained by suitable mixtures of red, green and blue light reflected together to the eye.

As is well known, coloured light can be obtained by passing the white light through a piece of glass of the desired colour. This coloured glass is obtained by fusing chemical substances in ordinary glass during its manufacture. These substances have the property of absorbing all the coloured rays except those of the colour of the glass. Thus a red glass allows only the red rays, and those near the red in the spectrum, to pass through it and all the other constituent colours of white light are absorbed. For this reason all white objects appear red when illuminated by a lamp which has a red glass or " filter " in front of it.

Some idea of the colours which surfaces reflect can be obtained by shining light on them through differently coloured screens. It is found that most coloured substances reflect a mixture of coloured rays. For example, a purple material appears blue when blue light is shone on it but red when red light is used. This indicates that blue and red rays are reflected from the purple surface. A green

light, however, is not appreciably reflected from such a surface, most of it is absorbed and the surface then appears dark, almost black, in a green light.

Sunlight and the white light from a gas or electric lamp appear more or less the same to the eye, but a noticeable difference is apparent when each is passed through a prism (Fig. 115) and their spectra compared. It will be seen that there is a different proportion of blue to red in the two spectra, there being more red and less blue in the gas or electric light than in the sunlight. This difference in the constitution of white light has an appreciable effect when viewing colours in artificial light. For example, a purple material reflects the blue and red rays of the white light which fall on it (page 118). When sunlight shines on a purple surface the surface reflects more blue but less red than it does when gas or electric light is used, since there is more blue and less red present to be reflected. Hence the purple appears to be of a different tint in the gas-light. Two coloured substances which match in daylight may not do so by artificial light if their colour is due to the reflection of rays of different colours. Thus a yellow which is produced by the reflection of yellow light might not match with one produced by red and green rays because of the different proportions of red rays in the daylight and artificial light. This makes it undesirable to choose colours in artificial light. Nowadays "daylight" lamps are used in many shops selling coloured materials, and they are so coloured that they give out more blue and less red light than do ordinary electric lamp bulbs, the proportions of the colouring materials used to colour the lamp being carefully selected so as to give out light which closely resembles sunlight.

When coloured paints, or pigments, are mixed the resulting colour is different from that obtained by mixing coloured lights. Thus when a white screen is illuminated by a red and a green light at the same time it appears yellow. But when red and green paints are mixed the result is a dirty brown colour. The light reflected from such a mixture is that which is not absorbed by either of the paints but that which is reflected by both of them. For instance, when blue paint is mixed with yellow the mixture is green, for green light is reflected by both the blue and the yellow pigments.

Infra-red Rays.—When visible light falls on a surface and is absorbed there is a slight rise in the temperature of the surface showing that heat is being produced. The astronomer Herschel endeavoured to find out which colours produced the greatest heating

effect when sunlight is dispersed. He found, by placing a thermometer in the sun's spectrum, that more heat was produced in the red than in the violet end. He made a more important discovery when he moved the thermometer out of the spectrum beyond the red end, for there he found that the heating effect produced was even greater than in the spectrum itself. He concluded from this that the effect was due to rays, similar to light rays, but invisible to the eye.

These rays in the spectrum, which are less refracted than ordinary light rays, are called infra-red rays. They are produced by glowing electric lamps and are much used in medical work, for they penetrate the flesh before they are absorbed and produce heat. Photographs may be taken by the infra-red sun rays in the same way as with ordinary light only using a special filter and plates. The visible light is cut off by means of a screen in front of the camera and only the infra-red rays pass on to the plate. Such photographs are clearer than those taken by the use of the ordinary rays, which are more scattered by particles in the air than are the infra-red rays.

Radiant Heat.—Infra-red rays and other heat-producing rays are known as "radiant heat." These heat rays have many of the properties which are associated with the light rays. They travel in straight lines, thus a wall shades the ground within its shadow from the sun's heat as well as from its light. They are reflected, so that polished reflectors can be used with electric fires to concentrate the heat in a particular direction. A burning-glass brings the sun's heat rays to a focus, showing that they are refracted, and a piece of paper may be lit by this means. In dry weather vegetation may be set alight in this way by the refraction of the sun's heat rays through broken glass bottles left about; this is a frequent cause of woodland fires. Radiant heat travels at the same speed as light, 186,000 miles per second. During an eclipse of the sun the heat rays are cut off together with the light rays, and as both travel at the same speed the effects are felt on the earth simultaneously.

Heat rays supply heat only when they are absorbed. A black surface absorbs all the rays and becomes hotter than a reflecting surface such as a white polished surface, provided the rays fall on the two surfaces equally (page 90).

Light is only given out when a body is heated to a relatively high temperature; radiant heat is given out even at ordinary temperatures and causes the loss of heat by radiation when any object is above the temperature of its surroundings.

Ultra-Violet Rays.—The different colours of the spectrum of the sun affect a photographic plate to a varying degree. The red part of the spectrum affects the plate the least and the other end of the spectrum, the violet part, the greatest. But the effect is even greater when the plate is put beyond the violet end, out of the visible part of the spectrum. It is caused by rays which have an even greater photographic effect than violet rays. They are known as ultra-violet rays (ultra = beyond) since they are formed beyond the violet in the spectrum and are more refracted than light. These rays, as well as the visible light and the infra-red rays, are emitted by the sun.

Ultra-violet rays are best known at the present time for their health-giving and curative powers. The exposure of the skin to the sun's rays enables the body to build up supplies of one of the vitamins which is necessary for good health (page 262), hence the value of sunbathing. The ultra-violet light which is used for so-called sun-ray treatment is produced either by an electric arc between rods of tungsten or carbon or by the passage of an electric current through a tube containing mercury vapour. The tube is made of quartz and not of glass because glass does not transmit the rays.

A special form of glass called Vita glass is now often used for windows. It allows ultra-violet light to pass through it, and so gives the benefit of the rays indoors.

X-rays.—In 1898 Röntgen was experimenting with the passage of currents of electricity through a tube containing a gas at a very reduced pressure. He noticed that a photographic plate near the tube became fogged even though it was well wrapped up. Further investigation showed that rays were being emitted which could pass through many opaque objects such as wood, paper and flesh, but not so easily through metal or bone. Use is made of this property in X-ray photography. The X-rays are allowed to fall on part of the body and pass through the fleshy portion but are absorbed by the bones. The rays passing through affect a photographic plate and thus an X-ray photograph shows the position of the bones. Metals are also shown, e.g. the ring and the lead shot in Fig. 116.

Rays with many similar properties are given off continually by the rare substance known as radium and other radioactive substances. These rays penetrate most substances and are used in the treatment of certain diseases, for they have the effect of destroying living tissues such as the diseased tissues in cases of cancer.

Wireless rays are produced electrically at the transmitting station and travel in wave motion at the same speed as light. Indeed light rays and the other rays mentioned are all electrical in origin and all travel in a wave motion through space. They are all alike in

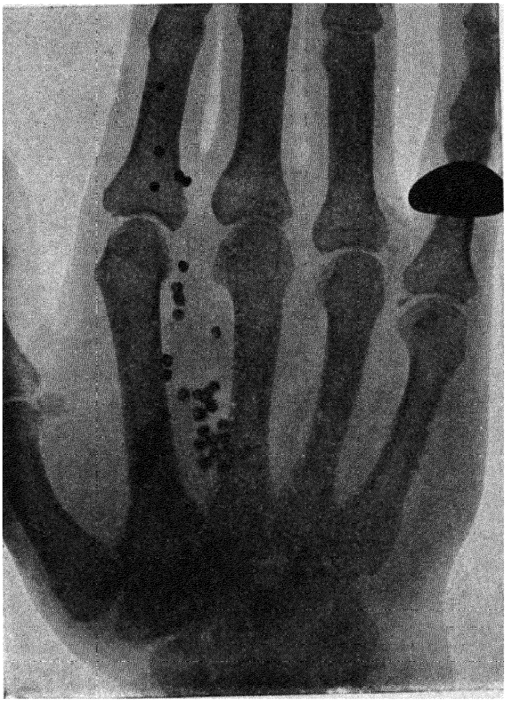


FIG. 116

many properties: they travel in straight lines at 186,000 miles per second, and they can be reflected, absorbed and transmitted. All are forms of radiation and travel through the ether. The difference which characterizes each type of wave is one of wave-length, i.e. the distance from crest to crest of the electrical disturbances. This difference is shown in the following table:

TABLE II

THE WAVE-LENGTH OF ETHER WAVES

Radium Rays.	X-Rays.	Ultra-Violet Rays.	Light Rays.	Infra-Red Rays.	Heat Rays.	Wireless Waves.

————increasing wave-length————→

CHAPTER XIII

SOUND

THE edge of a ringing cycle-bell can be seen to be quivering; it appears blurred and the to-and-fro movements taking place can be felt when it is touched. The bell vibrates as it rings, and the sound dies away as the vibrations cease. All sounds are produced by rapid to-and-fro movements or vibrations of the object causing them.

Bells are specially designed to give out sound and so are tuning-forks, musical instruments and our own organs of speech. But most things vibrate and produce sounds when they are disturbed. For instance, footsteps cause the ground to vibrate and so can be heard, and animals, however quietly they move, cause rustling sounds as they brush past the objects in their way. Animals are provided with a sense of hearing which enables them to detect and distinguish between the movements which cause varying sounds and so they become aware of what is happening at a distance from them.

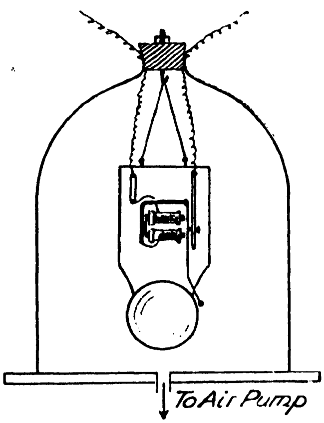


FIG. 117

Sound travels through the air to the ear. It needs some material medium throughout its path, for it cannot pass through a vacuum. The need for this medium can be shown by means of a small electric bell suspended by elastic strings from the top of a glass cover (Fig. 117) which is placed on the plate of an air pump. The bell is set ringing and is plainly heard, but as the air is pumped out of the vessel the sound becomes weaker and weaker. Finally it becomes inaudible, though the hammer is still to be seen striking

the bell. When the air is let in again the sound again becomes audible. Without the air we should not be able to hear, at least in the way we do now, for it is through the air that most sounds reach us. Other substances as well as air transmit sound. For instance, in the experiment just described, if the bell is resting against the glass cover the sound passes through the glass to the air outside and so is heard.

There are, therefore, three essentials in connection with sound; a vibrating source to produce it, a material substance or medium (which is usually air) to transmit it, and the ear to receive it. The air is set in vibration by the source of sound and the vibrations cause corresponding vibrations of the ear-drum. This consists of a thin membrane which is much like the parchment of an ordinary drum. The vibrations are passed into the interior of the ear and the sensation of hearing is produced (page 334).

Speed of Sound.—Sound travels in air at a speed of about 1,100 feet per second, a very low speed indeed when compared with the speed of light, which is 186,000 *miles* per second. Therefore when sound and light are produced simultaneously the light is perceived long before the sound is heard. Thus the flash of lightning is seen almost instantaneously, the time it takes in travelling being practically negligible, but the noise of the thunder which accompanies it is heard some time later. The noise of the thunder travels at approximately one mile in five seconds and so the distance of the centre of the thunderstorm can be calculated approximately. For each five seconds which elapses between seeing the flash and hearing the noise the lightning is about one mile away.

The flash of the gun is seen before the noise of the explosion is heard and the steam from a siren is seen long before the hoot is heard. A rifle-bullet travels faster than sound but not as fast as light, and so a bullet reaches its target after the flash has been seen but before the noise of firing is heard at the target.

Sound travels through other materials besides air but not at the same speed. Footsteps a long way off can be heard with the ear close to the ground, the sound having travelled through the earth. Submarines can be detected at a great distance since the noise made by the engines travels through the water. An interesting comparison of the difference of the speed of sound in air and in iron can be made by striking an iron railing. A person some distance away with his ear to the railing, hears first of all the sound which has

travelled through the iron and later the sound which has travelled at a slower speed through the air.

The method by which sound travels can be explained by considering what happens when a drum is struck. The skin of the drum moves backwards and forwards rapidly. As it moves forward the particles of air near it are pushed forwards and strike those in front of them, setting them in movement, but they themselves stop. In this way the movement is passed along. As each layer of particles moves forward it increases the congestion of the particles. This congestion is called a compression. The process is similar to what happens when an engine backs into a long line of trucks. The first truck is pushed backwards and strikes the next, and then it comes to rest. The second repeats this in striking the third, and this happens throughout the line of trucks. In effect the push of the engine on the first truck has been passed on all along the line. The compression of the air particles, as it travels in a similar way, gives rise to the crest of a sound wave. When the skin of the drum moves forward again it again compresses the air as before and sends out another compression. The distance between this compression and the previous one, that is, the distance from crest to crest of the waves, is called the wave-length. It is the distance that the wave travels while the source of sound makes one vibration. The compressions reach the ear and cause the drum of the ear to vibrate and so the sound is heard.

Reflection of Sound.—Sound waves can be reflected just as waves of water are reflected and sent back when they strike against a wall or the river's edge. As in the case of the reflection of light it can be shown that the angle of incidence equals the angle of reflection. Thus two cardboard tubes are arranged as shown in Fig. 118 with one end of each facing a vertical plate and a screen separating them. Each tube is inclined at the same angle to the normal and a watch is placed as shown. The sound of the tick travels down the cardboard tube, hits the plate and is reflected through the other tube.

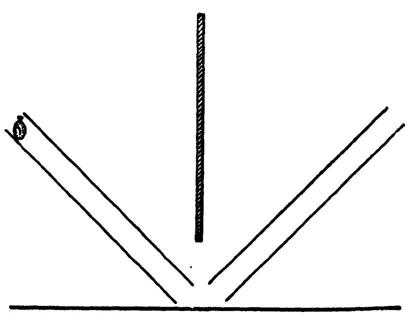


FIG. 118

Echoes are caused when waves of sound are reflected from a

surface such as a cliff or a high wall. When a person facing a cliff shouts out, this sound travels to its surface and is reflected back. The sound takes time in travelling there and back and hence the echo is heard some little time after the person shouted. This setting up of echoes is made use of by a ship at sea near a cliff during a fog. The ship's siren is sounded and the sound waves travel outward. The time elapsing between the siren sounding and the echo being heard is noted. Suppose this is two seconds. In that time the sound has travelled from the ship to the cliff and back again, a combined distance now known from the time taken to be 2,200 feet (see page 124) so that the ship is 1,100 feet from the cliff.

Reverberation.—Echoes are produced when the sound waves strike a good reflecting surface such as the walls, ceilings or even the floors of a room. The reflection of sound waves, with the subsequent echoes, is very noticeable in a cathedral or large church, especially when the organ is being played. The waves from a single note are reflected from the roof, then from a wall, then from a rafter and so on, so that a succession of echoes is formed. When a succession of echoes is formed from one sound the effect produced is called reverberation. Obviously reverberation interferes with the proper hearing of speech because the echoes of previous syllables are being heard while later ones are being produced, but some reverberation is effective when music is being played. Many surfaces, however, absorb sound instead of reflecting it, carpets, curtains, coco-nut matting, etc., being good absorbers. The presence of carpets and curtains accounts for the well-known difference between speaking in a well-furnished room and one with bare walls and floors.

Noise.—The mechanical inventions of modern times have greatly increased the miscellaneous sounds which are classed as noises. Noises can sometimes be stopped at the source by preventing the vibrations which cause them. This is often possible in machines of careful design; compare the noise made in the running of a Rolls-Royce motor-car with that made by a mass-produced car. Another method of prevention is to absorb the sound waves by sound insulators. Thus the intensity of sound passing from one room to another can be decreased by using in the wall, or floor spaces, such insulating materials as coke-breeze and felt. Sound is transmitted in buildings sometimes because it is conducted along the long steel girders which are frequently used. When instead of long girders shorter ones are used, the small air gap between each length makes a considerable difference to the

volume of sound transmitted, for sound does not readily pass from one material (steel) into another (air) of different density but is reflected back from the surface. This also accounts for the sound-insulating properties of porous substances or small pieces of material.

Sound waves spread outwards in all directions in air. Owing to this spreading the waves become weaker as the distance from the source increases. If the waves are prevented from spreading the sound is heard more distinctly at a distance from the source. Thus sound can be passed along a rod with little loss of intensity for the waves keep to the material and do not spread. A string telephone, consisting of two tin cans joined at their bases by string, works on the same principle. A person speaks into one can and the sound is transmitted along the long piece of string to the other can and can be heard there. A speaking-tube works similarly and so does a doctor's stethoscope, the hollow tube of which confines the sound waves to the air inside by repeated reflections. Sound waves are reflected from the sides of an ear-trumpet, and are concentrated at the smaller end. The large ears of animals have a similar effect in concentrating the sound.

Vibrations.—The vibrations which produce sound are so rapid that they cannot be separately distinguished, although the blurred outline of a vibrating violin string can be seen. These vibrations are similar to others which can be obtained by using the apparatus shown in Fig. 119. This consists of a piece of spring steel, about a foot long, which is clamped almost at the bottom. The steel vibrates when it is plucked but the vibrations are very slow and no sound is heard. The number of times it vibrates per second, i.e. moves from " a " to " b " and back again, is called the frequency, while the distance travelled from " a " to the mean position, O, is the amplitude of the vibration and depends on the strength with which the steel was plucked. The steel spring is moved farther down in the clamp and is again plucked. The steel vibrates more rapidly and possibly a low note is heard. The length of the vibrating steel is again shortened by lowering the steel farther down in the clamp and when plucked it vibrates still more rapidly. As the number of vibrations per second increases, i.e. as the frequency

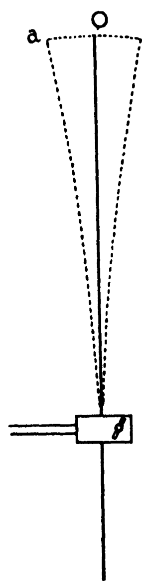


FIG. 119

of vibration increases, the pitch of the note which is given out increases.

Pitch depends on frequency, the greater the frequency the higher the pitch.

The loudness of the note given out by the plucked steel depends on how strongly the steel is plucked and the stronger it is plucked the greater is the amplitude of the vibration and the loudness, but the pitch of the note is the same, thus:

Loudness increases with the amplitude of vibration, though the frequency and the pitch is not affected. The loudness also depends on the distance of the source of sound from the person hearing it, for sound waves spread considerably in the air and lose some of their intensity on their way.

Stringed Instruments.—The vibration of strings in many of our musical instruments can be studied by using a monochord (Fig. 120). The string vibrates when it is plucked or bowed and produces a musical note. The effective length of the string is that between the bridges A and B, and on reducing this length, by moving one of the bridges, the note it emits is *increased* in pitch. For instance, when the length is halved the octave of the previous note is heard. The pitch of the note depends on the frequency of vibration, which is inversely proportional to the length of the wire.

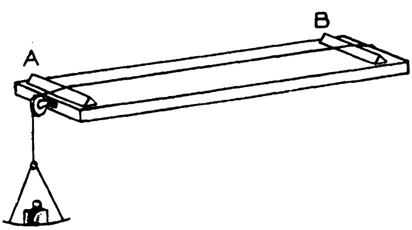


FIG. 120

The tension in the string can be increased by adding more weights to the pan, and when this is done, the pitch again increases as does the frequency. Thus the pitch of a note and the frequency of vibration increase with the tension in the string.

The wire may now be changed for one of thicker material and it will be found that the heavier the string, the lower in pitch is the note produced by wires of the same length.

In a musical instrument such as a piano a higher note may be produced by decreasing the length of the wire used, by increasing the tension on it or by decreasing the mass of the wire. The designer of a piano uses all of these ways in obtaining the notes. The highest

notes are obtained by using strings in which the tension is high. The lowest notes are produced by loading the strings, which is often done by winding them with copper wire (so that they are not inconveniently long) and so increasing the mass. In the violin or 'cello all the strings are of the same length from the bridge to the far end or " nut " of the finger-board and the difference in frequency is obtained by using strings of different thickness and by varying the length of the vibrating portion of the string. This length depends on the distance from the bridge to the point where the string is depressed by the fingers on the finger-board. The tension in each string is controlled by means of a peg.

Quality.—The string of an instrument such as a violin or 'cello vibrates as a whole when it is bowed and gives out a characteristic note. While the string is vibrating if the finger is lightly pressed against it, at midway, a note one octave higher than the previous note can be heard but it is by no means so loud. This illustrates that at least two different notes are being emitted at the same time, one corresponding to the vibration of the whole string and a note an octave higher which has a frequency of twice the other note and corresponds to the vibration of the string in two equal parts. In addition to these two notes other ones are being produced at the same time, the frequencies of these notes being simple multiples of the lowest note. The note corresponding to the full vibration of the string is called the fundamental and all the other notes are known as the harmonics. A bowed violin string is therefore giving out not only the one fundamental but other notes as well, all of which harmonize. The presence of these harmonics give the violin notes their characteristic sound or quality. Harmonics are produced by most musical instruments. They depend on the type of instrument and its design, so that each instrument has a quality or " timbre " of its own.

Musical Scales.—The ear is sensitive to sounds which are produced by vibrations varying in frequency from about 30 to 15,000. This is a very wide range. A string vibrating with a frequency of 256 produces the note middle C of the piano. Then 256 sound waves are being produced each second, and since sound travels at the rate of 1,100 feet per second there will be 256 waves in this distance, hence one such sound wave has a length of $\frac{1,100}{256} = 4\frac{1}{4}$ feet (approximately).

Top C note of the piano which is an octave higher than middle

C is produced by a frequency of $2 \times 256 = 512$ and the wave-length of the sound waves is half that of the waves of middle C. It was mentioned, page 128, that the octave note of one of lower pitch is always produced by vibrations having twice the frequency and the octaves of middle C which can be heard by the human ear (see above) are produced by vibrations with the following frequencies:

32, 64, 128, $\boxed{256}$, 512, 1,024, 2,048, 4,096, 8,192.

Hence the maximum number of audible octaves is nine; keys are provided on a piano to produce only seven octaves. The different notes are produced on a piano by using strings which, when struck by the hammer, vibrate at different frequencies because they are of different lengths and masses. These strings are chosen so that the number of vibrations of one string is a definite multiple of that next to it. There are twelve semitones in the scale, one tone, or two semitones, between doh and ray, the same between ray and me, but me and fah are only one semitone apart, and so on as shown:

Notes:	*d*	*r*	*m*	*f*	*s*	*l*	*t*	*d*	
Semitones:	2	2	1	2	2	2	1		= 12.

Just as there is a constant ratio between the frequencies of one note and its octave so there is also a constant ratio between the frequencies of two adjacent semitones. The ratio in the case of the octave is two; in the case of the semitones it is 1·059. The frequency of middle C is 256, that of the semitone above it is $256 \times 1{\cdot}059$ and of the next semitone $256 \times 1{\cdot}059 \times 1{\cdot}059$ and so on. This ratio of 1·059 is chosen so that the octave follows the twelve semitone intervals; 1·059 multiplied by itself twelve times equals 2, i.e. $(1{\cdot}059)^{12} = 2$. This number, 1·059, is known as the frequency ratio and each string of a piano is made to give a vibration 1·059 times greater than its neighbour down the scale, including the black keys. The advantage of this arrangement is that a musical scale can be started on any one note on the piano since the frequency of each note differs from its neighbour in a like degree (i.e. by the ratio of 1·059). Each scale, no matter what "key" it is in, is similar to any other except for a difference in general pitch.

Certain pairs of notes produce an agreeable effect when they are played one after the other in a melody or when they are sounded together as in a harmony. The two notes harmonize well when their frequencies are simple ratios of each other. Thus middle C

has a frequency of 256, and top C one of 512, i.e. just twice as great. These two notes will harmonize. Note E has a frequency of 320, i.e. $320/256 = 5/4$ times larger than 256. This is a simple ratio and notes C and E harmonize. This ratio of frequencies, 5/4, is called an interval, this particular interval being a major third. The interval of a perfect fifth is 2/3, thus a perfect fifth interval is from C (256) to $256 \times 3/2 = 384$, the frequency of note G. (The frequencies of the notes on the piano differ slightly from those calculated from such simple ratios and do not give perfectly " true " scales but they are sufficiently close for the difference in pitch not to be detected except by trained musicians.)

Resonance.—A swing is usually set moving by pushes so timed that each adds to the movement. Though each push has little effect in itself, if the pushes are continued, a considerable movement is finally produced. The setting up of vibrations by correctly timed impulses is called resonance. There are many examples of such vibrations being produced. When a car travels at one particular speed a vibration may be set up which is not set up at other speeds. This is because the moving parts of the engine provide impulses which are of the same, or nearly the same frequency as that natural to the vibrating part and this happens just around one speed.

Resonance is particularly important in connection with sound. It may be illustrated by holding a vibrating tuning-fork over a glass tube dipping down into water. As the tube is raised or lowered there is one position which gives a reinforcement of the sound of the fork due to the resonance of the column of air in the tube. The frequency of the fork and the natural frequency of the tube are then the same. Tuning-forks are often placed on special box resonators of the same natural frequency as the fork, and the box makes the sound much louder. The body of a violin produces resonances with harmonics in the notes produced by the strings and this helps to give the instrument its particular quality of tone. The violin body has a number of frequencies at which it may naturally vibrate so that it does not resonate at one frequency only. A good violin has many resonances and does not reinforce them unduly. A bad violin has resonances at a few frequencies and reinforces them too much. The same is true of a bad loud-speaker in a wireless set.

Organ Pipes.—A column of air, as shown by the experiment on resonance, has a natural frequency of vibration. This frequency, and hence the pitch of the note it gives out, depends on the length of the air column. This can be shown by filling a number of test-

tubes with water to different levels and fitting them with corks. Each tube gives out a particular note when the cork is pulled out, the shorter the column of air in the tube the higher is the pitch. The same note as that produced when the cork is pulled out is produced by blowing through the mouth across the top of the tube. The flue type of organ pipe (Fig. 121) yields a note when treated in a somewhat similar way. Air is blown in at the bottom, A, is directed out of the small slot at B and blows across the mouth of the pipe, striking the lip at C. The pipe emits a note the pitch of which depends on the length of the pipe. Large organs have numerous flue pipes of varying lengths, the lengths being carefully chosen to give notes of the frequency required to yield a scale. Organ pipes, like vibrating strings, give out harmonics or overtones and these harmonics determine the characteristic "quality" of the organ note.

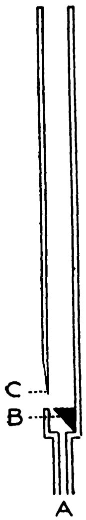


FIG. 121

A reed is used in some organ pipes (Fig. 122). It consists of an oblong metal plate fastened at one end which nearly covers a hole of the same shape. The reed is set vibrating by blowing air through the hole as shown by the arrows. In the mouth-organ, the harmonium and some other instruments the free vibrations of the reed produce the notes; in others, as in the pipes of an organ, the reed causes an air column to vibrate and the vibrations of the reed then follow the natural vibrations of the pipe or tube. This is the case also in some wood-wind instruments including the oboe and clarinet. The "quack" which is sometimes produced by an unskilful player is the natural tone of the reed when vibrating freely.

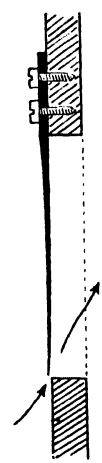


FIG. 122

Wind Instruments of the Orchestra.—The vibrations of the air inside the tube of a wind instrument are excited by the breath of the player. With the flute, the player blows across a hole in the side and the vibrations are set up in a similar way to those in a flue organ pipe. The player does not fix the note he produces by the blowing and the same is true with reed instruments. In sounding a bugle, however, and other brass instruments, the player uses his lips as a reed and makes vibrations corresponding to each note sounded.

An air column is capable of vibrating at its fundamental frequency and at various multiples of this frequency giving the harmonics. (These are capable of being excited more easily when there is a flare to the tube as in a bugle.) The bugle player is limited to the notes corresponding to these free vibrations of the air in the instrument. He produces the required vibrations by means of his lips and the sound is reinforced by resonance.

The range of notes which may be played is increased in most instruments by varying the length of the vibrating air column. This is done in several ways. In a trombone a sliding tube increases and decreases the length of the air column as it is pulled out and in. Another way is by means of valves which add short lengths of tube to the column as in the cornet.

The method used in wood-wind instruments is to bore a series of holes in the tube. The air column vibrates as it would if it extended from the mouth-piece to the first open hole in the column. For example, the lowest note given by a tin whistle is that due to the full air column vibrating and is obtained when all the holes are closed, and the highest note when the hole nearest the mouth-piece is open. Sometimes the holes are provided with pads which cover them when the fingers press on them, e.g. the Boehm flute. This is absolutely necessary if, as on the saxophone, the holes are too large to be covered by the fingers alone, or when some of the holes do not lie immediately under the fingers. In the latter case the pads are controlled by keys brought within the range of the fingers. On the bassoon the holes are drilled obliquely to be in reach and for this reason many notes on this instrument need "humouring."

Members of an orchestra usually "tootle about" before the performance. This is done to warm the instruments, which give the correct pitch at the temperature of the breath. Warm air is less dense than cold air, the mass of air in a warm tube is therefore less than that in the same tube when cold, and vibrates more quickly.

The Gramophone.—As a gramophone record rotates the needle remains in a groove which runs in a spiral from the outside to the inside of the record. The groove, when highly magnified, shows a series of waves which make the needle vibrate sideways as the turn-table moves round. This vibration is passed on to a mica sheet in the sound-box which sets the air in motion, so reproducing the sound from which the record was made. The original record is made on soft wax. The sounds which are to be recorded set up

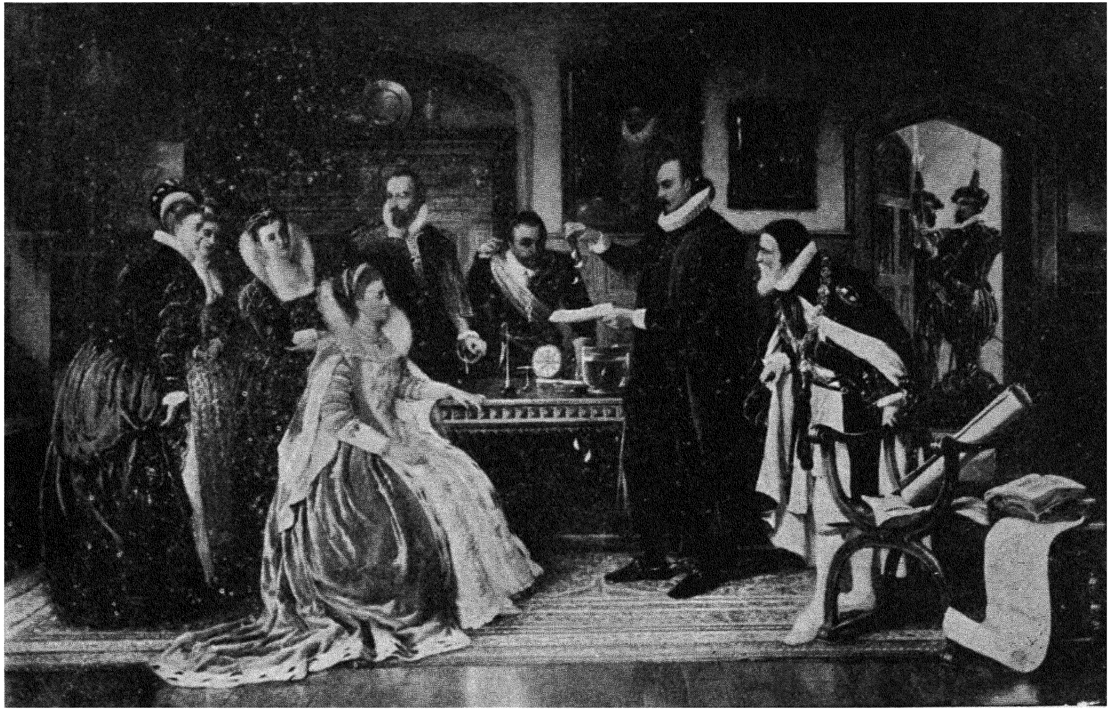
vibrations in a mica sheet and are communicated to the needle. As the soft record moves the needle cuts a groove in it which has the waves corresponding to the vibrations of the needle, the spiral form being produced by a movement inwards of the needle. The soft wax record is used to make the moulds from which the final records are cast.

CHAPTER XIV

ELECTRICITY

IT has long been known that amber when rubbed with wool attracts small objects like paper and straw. Many other substances have this property, e.g. glass, vulcanite, sealing-wax and ebonite. The painting which is reproduced in Fig. 123 shows Dr. Gilbert, physician to Queen Elizabeth, demonstrating this property to her in the presence of courtiers. Our word electricity was coined by Gilbert from the Greek name for amber which is electron. Besides attracting light objects those substances which behave like amber attract or repel each other. Thus a glass rod is rubbed with a silk cloth and suspended so that it can swing horizontally. When the end of another glass rod which has also been rubbed with silk is brought near the end of the suspended rod they repel each other, the suspended rod swinging away from the other. If instead of a glass rod, an ebonite rod which has been rubbed with fur is brought near the suspended glass rod the two rods attract each other. Both rods are charged with electricity but the charge on the ebonite evidently is different from that on the glass. The glass is said to be positively charged while the ebonite is said to be negatively charged. Two kinds of electricity are recognized, positive electricity and negative electricity.

A ball of copper or brass can be charged by flicking it with fur, provided it is supported on a glass or ebonite stand, but when it is touched the charge passes through the metal to the hand and through the body to the earth. The ball loses its charge and a small spark may be seen as the discharge takes place. Brass and the human body conduct electricity, while substances like ebonite and glass do not. This is why the latter two may be charged while held in the hand, while the brass ball cannot. Substances through which electricity flows, such as brass and other metals, are called conductors. Substances such as ebonite and glass are non-conductors or insulators.



Courtesy of Colchester Corporation

FIG. 123

Dr. William Gilbert demonstrating his Experiments before Queen Elizabeth
(From a Painting in the Council Chamber, Colchester Town Hall)

Lightning is a discharge of electricity through the air between one charged cloud and another or between a charged cloud and the earth, the clouds becoming electrified, probably by streams of air rubbing together. A lightning conductor consists usually of a thick strip of copper reaching higher than the building it protects and connected at the bottom to a plate in the earth. In the event of lightning striking the building the discharge passes down the conductor rather than through the building itself.

Electricity as we use it to-day is in the form of electric currents. They consist of charges of electricity in motion and are supplied by dynamos and batteries. The discovery which led to the first practical method of producing electric currents was an accidental one. Galvani, an Italian, had noticed that when a discharge of electricity passed through a frog's leg it twitched. He tried the effect of lightning in producing this effect. To do this he fixed a frog's leg to an iron railing by means of a brass hook and noticed that the leg could be made to twitch simply by touching the railing with it. Actually he had produced an electric current by means of the two dissimilar metals, the brass and the iron, which were connected together by the frog's leg. Volta, another Italian, followed up the discovery by inventing a cell consisting of two metallic plates, one of copper and the other of zinc, with a cloth soaked in brine placed between them. The cell enabled a continuous current of electricity to be obtained by means of chemical action, and modern batteries produce electricity in a similar way. But chemical action of this nature could not supply the large quantities of electrical energy needed to-day. This was made possible by the discoveries of Michael Faraday and others which led to the dynamo or electric generator. Dynamos driven mechanically are the sources of the electric current of the supply mains.

Circuits.—A current of electricity can only flow when there is a path provided for it. This path must be made of conducting materials and must also be a continuous one. When this unbroken conducting path is joined either to a battery or to the mains supply it forms a complete circuit. A simple form of circuit is shown in Fig. 124 and in describing it some of the electrical terms used are given. It consists of an accumulator, a switch and a lamp, connected together by copper wires or leads. When the switch is closed the circuit is made and a current flows, as shown by the lamp glowing. The circuit is broken by opening the switch in which the metallic contacts separate, leaving a gap between them. The

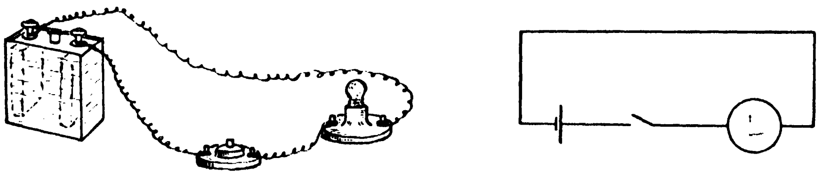


FIG. 124

battery usually has its terminals or poles marked + and —. The positive terminal is often coloured red while the negative one is coloured black and the current is said to flow from the positive to the negative pole of the battery. The connecting leads are made of copper, which besides being a good conductor, is flexible. The wire is covered with an insulating material such as cotton, silk or rubber. A circuit diagram in which symbols

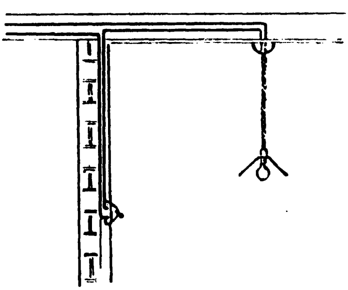


FIG. 125

are used to represent the various parts is also shown in Fig. 124. The way the cell is represented should be noticed: the longer line is usually taken to represent the positive pole and the shorter line the negative pole of the cell. The corresponding wiring to a lamp and switch connected to the supply mains is shown in Fig. 125.

The Flash-lamp.—There is a complete metallic path, Fig. 126, from one terminal, A, of the dry battery to the other, which is the metal base of the battery, E. The bulb is of the single pole type, i.e. one end of the filament wire of the lamp is connected to the lead stud at the base of the bulb, the other end being connected to the brass outer casing. The stud is insulated by pitch from the outer case of the bulb. The circuit can be traced from Fig. 126, all insulated parts being shaded. The current flows from A, which is in contact with the lead stud, through the filament and out of the metal

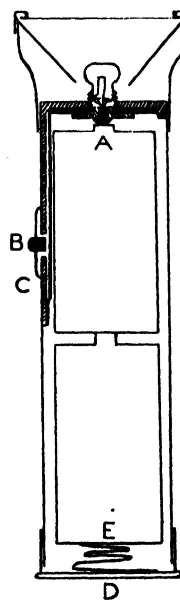


FIG. 126

casing of the bulb, which is in contact with the brass strip shown in

a thick line. The circuit is complete when the stud B is pressed so that it comes in contact with the brass strip. The current then flows through B to C, then along the metal casing of the torch to D and then along the spring to the base of the battery, E.

Effects of an Electric Current.—It is well known that electric lamps connected to the house supply get warm after the current has been flowing through them for a short time. The effect of the current is to heat the filament wire, which soon becomes white hot or incandescent, thus giving out light. But as well as giving light and heat (see also page 226) electricity can be used to magnetize pieces of iron and steel. This magnetic effect, as will be seen later, has many important applications.

The Magnetic Effect of a Current.—Fig. 127 shows a glass tube about 6 inches long around which has been coiled about a yard of thin copper wire. Such a coil is known as a solenoid. When a steel knitting-needle is placed inside this solenoid and a current of electricity is passed through the wire, the needle becomes magnetized. That is, it then has the property of attracting small pieces of iron. A piece of soft iron is also magnetized in this way, but

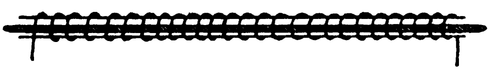


FIG. 127

the iron differs from the steel in that it loses its magnetic properties when it is removed from the coil, or when the current is switched off. The steel, however, becomes a permanent magnet. Permanent magnets are now made of special alloys containing other metals besides iron, cobalt and nickel being principally used. A few substances, such as iron, steel, cobalt and nickel, which can be magnetised and are attracted by magnets, are called magnetic substances. All others are non-magnetic substances.

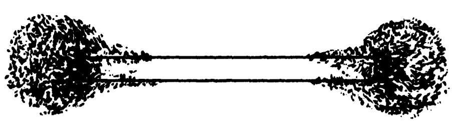


FIG. 128

Properties of Magnets.—Fig. 128 shows a magnet which has been dipped in iron filings and then removed. It will be seen that the filings are clustered mainly about the two ends of the magnet

and are directed mainly towards two points, one at each end. These two points are called the poles and are situated inside the magnet at a small distance from the ends. When a magnet is placed in a stirrup and suspended by means of a fine silk or cotton thread it sets itself so that the line joining the poles is approximately in a north and south direction. After being set moving the magnet finally comes back to the same direction with the same end pointing north. This end is called the north-seeking pole, or simply the north pole, and the opposite end is called the south-seeking or south pole. The north pole of a bar magnet is usually marked with the letter N. A compass needle, Fig. 129, behaves in the same way as a suspended magnet. It consists of a magnetized strip of steel,

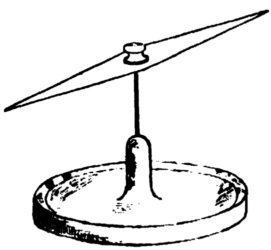


FIG. 129

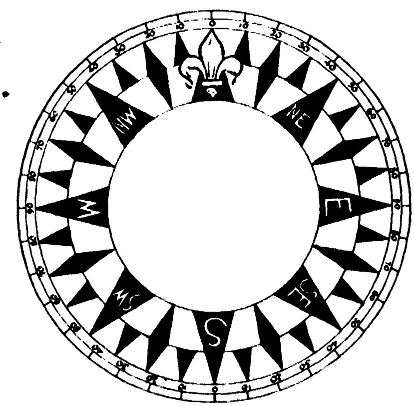


FIG. 130

pointed at the ends and pivoted so that it moves horizontally. In a pocket compass this needle is mounted inside a brass case and moves over a card showing the "points of the compass" (Fig. 130). The use of the compass in finding direction is mentioned later.

When the suspended magnet or the compass needle has come to rest, and another magnet is brought near to one end of it, one of two things happens. If the north pole of the magnet is brought near the north pole of the suspended magnet, the suspended magnet moves away, i.e. it is repelled. But if the south pole of the magnet is brought near the north pole of the suspended magnet the latter moves towards the other magnet, i.e. it is attracted. This can be summarized thus :

like poles repel, unlike poles attract each other.

A piece of suspended soft iron or unmagnetized steel behaves somewhat differently when a magnet is brought near it. Attraction always occurs no matter which pole of the magnet is brought near either end of the suspended piece of metal.

The forces between the poles of the two magnets are mutual, that is, each either attracts or repels the other. Also when a magnet attracts an unmagnetized piece of iron the iron equally attracts the magnet. Thus unmagnetized iron attracts either pole of a compass needle or a suspended magnet. Hence a method of testing whether a piece of steel is magnetized or not is to put it near each pole of a compass needle. If the steel is magnetized, one end of the needle is repelled. Repulsion is the surest test of a magnet.

Magnetic Induction.—The attraction of the suspended piece of soft iron is explained by the fact that the magnet converts the iron into a temporary magnet by a process known as induction. The pole of the magnet induces an opposite pole in the iron at the end nearest it and a like pole at the other end of the iron. Thus the two ends nearest each other, being unlike poles, are attracted. Whenever a magnet attracts iron, e.g. iron filings, Fig. 129, magnetism is induced into the attracted metal, thus each piece of iron filing is a small temporary magnet. But when magnetism is induced into a piece of hard steel some of it is retained, and steel bars can be made into permanent magnets by induction as follows. The steel bar (Fig. 131) is stroked from one end to the other by one pole of the magnet. This process is repeated many times, at the end of each stroke the magnet being lifted clear of the steel and brought down at the previous starting-point as indicated by the arrows. The starting-end of the steel is of the same polarity as the pole of the magnet which is used, while the finishing-end of the steel bar is of the opposite polarity.

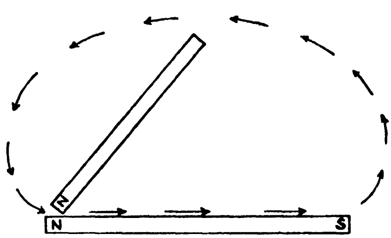


FIG. 131

Magnetic Fields.—The space round a magnet within the range of its magnetic influence is called a magnetic field and its presence may be shown by its effect on iron filings. A magnet is placed beneath a sheet of paper on which iron filings are sprinkled. The paper is then gently tapped and the filings set themselves into patterns of lines (Fig. 132). The filings are magnetized by induction

and set themselves in lines in definite directions. These lines are called lines of force. The lines may be plotted by using a small compass. This is put near one of the poles and the position of each end of the needle is marked. The compass is then moved so that one pole of the needle is over the same spot as the opposite pole previously was. This process is repeated either until the opposite pole of the magnet, or the edge of the paper, is reached. The points so obtained are joined together and other lines are obtained in a similar way. The direction of these lines is taken as the

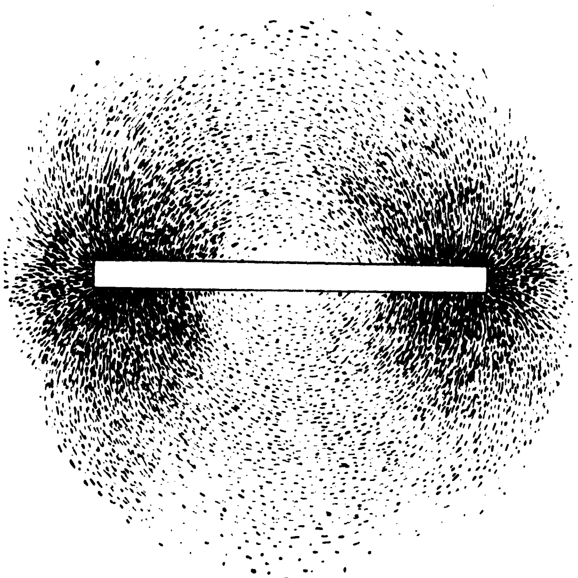


FIG. 132

direction the north pole points and is usually marked with an arrow. Thus the lines may be said to pass from a north to a south pole. The lines never cross. Other properties associated with them are illustrated in Figs. 133 and 134. The attraction of unlike poles (Fig. 133) can be viewed as a tendency for the lines to contract in length and the repulsion of like poles as a tendency for them to move sideways away from each other (Fig. 134). The lines are clustered close together near the poles where the magnetic effects are greatest and are sparse where the effects are weak, so that the distribution of the lines of force shows the strength of the field. Faraday made the lines of force give a clear picture of a magnetic field and its

strength. A strong field, such as that between the poles of an electro-magnet can be visualized as a large number of lines packed close together.

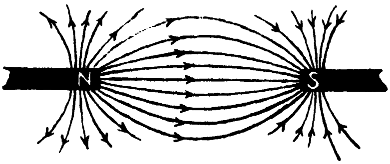


FIG. 133

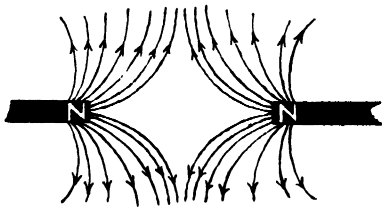


FIG. 134

Magnetic Screening.—There are no appreciable magnetic effects in the space within a ring of soft iron placed between the poles of a magnet (Fig. 135). The directions of the lines of force are indicated in the figure which shows the lines entering one side of the ring and leaving by the opposite side. They pass as magnetic lines through the iron, as shown by the dotted lines, taking this path in preference to passing through the air. Hence the inside of the ring is screened from the effects of the field. Use of this property is made by providing certain watches with soft iron cases; the inside of the watch is then unaffected by the presence of a magnet. It will be obvious that the case of a compass must not be made of iron; if it were the needle would be unaffected by the earth's magnetism. It is interesting to note that the hull of a submarine acts in a similar way to the ring of soft iron so that the inside of the vessel is screened from the earth's magnetism and a magnetic compass is therefore useless in a submarine. A further use is made of this property when storing bar magnets. Two bar magnets are stored in a box with the north pole of one at the same end as the south pole of the other. A piece of soft iron, called a keeper, is placed across these opposite poles. The lines pass through the iron and not through the air and this prevents the magnets from losing some of their power.

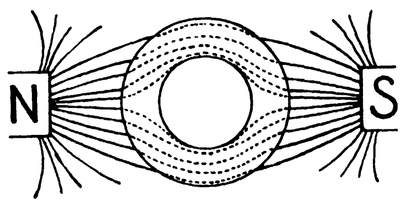


FIG. 135

The Earth as a Magnet.—The behaviour of a compass indicates the existence of a magnetic field in the neighbourhood of the

earth. The properties of this field can be accounted for by imagining that there is a relatively short magnet at the centre of the earth's sphere slightly inclined to a line joining the two geographical poles (Fig. 136). The direction of the lines of force of the earth's magnetic field is shown. It will be seen that the lines are vertical to the earth's surface at each magnetic pole. Elsewhere in the northern hemisphere they are inclined downwards and towards the north pole. At any place on the earth's surface the lines of force passing through it make an angle with the horizontal which is called the angle of dip. The value of this angle can be found experimentally by means of a needle pivoted so that it moves about a horizontal axis and sets itself in the direction of the lines due to the earth's field. (Since the north-seeking pole of a compass needle is attracted by the magnetic pole at the geographical north pole of the earth this magnetic pole is a south pole).

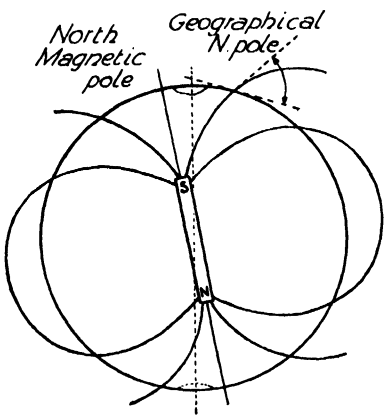
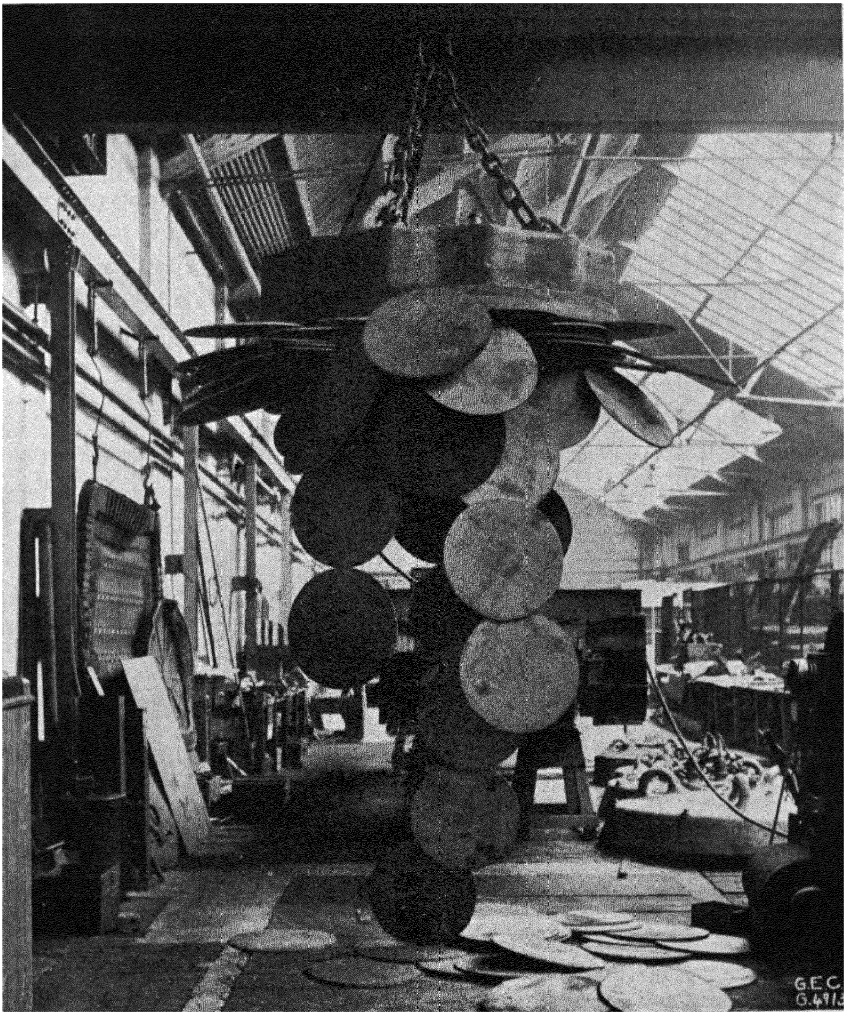


FIG. 136

Declination.—The compass needle points in the direction of the magnetic north and south poles and, as is seen from Fig. 136, this direction is not the same as that of a line joining the geographical north and south poles. In England the needle sets itself at an angle of about 11° west of the true north. This angle is called the angle of declination and varies at different parts of the earth. Allowance has to be made for declination when using a compass in navigation and special maps are made showing the declination at various parts of the earth.

The Compass.—The face or card of a pocket compass is as shown in Fig. 130 and the needle is a piece of magnetized steel. To use the compass it is put in a horizontal position and the brass case is turned until the needle makes an angle of 11° west with the north-south line on the face. The various points of the compass which are marked on the card then point in their true geographical directions.

A mariner's compass is somewhat similar but instead of having a magnetized pivoted needle the magnet is fastened underneath the



Courtesy of General Electric Co., Ltd.

FIG. 137

Electromagnet lifting Steel Discs

compass card. Thus the face moves with the magnet. Usually two or more short magnets are used instead of one and are arranged on either side of the centre of the card where it is pivoted. The moving part of the compass is often partly supported by a liquid round it, so that there is little friction at the pivot. The objects of the design are to give steadiness and freedom of movement. Gimbal mountings are used to keep the compass horizontal.

Electromagnets.—It has been seen that a piece of soft iron around which a coil of wire is wrapped becomes a magnet when a current is flowing through the wire, but ceases to be one as soon as the current is cut off. Use is made of this property in the electromagnetic crane and heavy loads can be moved from place to place by such a crane as shown in Fig. 137. The crane is lifting steel discs, and it is interesting to note the effect of induced magnetism which accounts for one plate hanging on to another.

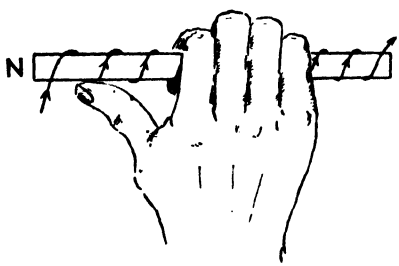


FIG. 138

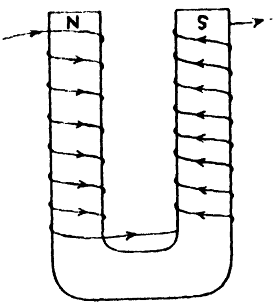


FIG. 139

The polarity of a magnet made in a solenoid can be found by the following rule. Place the fingers of the right hand round the coil in the direction of the flow of the current; the outstretched thumb then points to the north pole (Fig. 138). With this rule in mind the winding of the horse-shoe magnet (Fig. 139) should be inspected, for in order that opposite poles should be formed at the ends of it, the current must pass round the two coils in opposite directions.

The Electric Bell (Fig. 140).—A dry battery is used to work the bell and when the bell-push is pressed a current flows along AB through the screw C which is touching a spring attached to a piece of soft iron called the armature, D. This armature carries the striker. The current flows along it and then along EF, completing

its path round the horse-shoe electro-magnet to the terminal H and back to the battery. The electro-magnet attracts the armature and the bell is struck once. To get a continuous ring a " make and break " arrangement is required. It will be seen that when the armature is attracted the spring is drawn away from the screw C and so the circuit is broken. The armature is then no longer attracted and the spring attached at E pulls it back again until it touches C when the circuit is again completed. This process is repeated numerous times while the bell-push is being pressed.

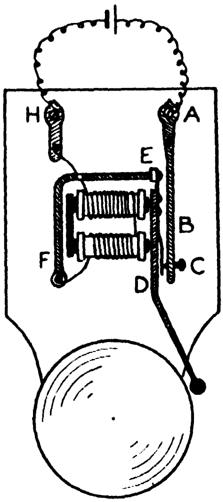


FIG. 140

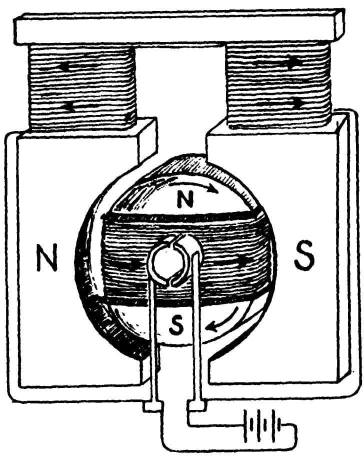


FIG. 141

The Electric Motor.—The parts of a simple motor can be seen from Fig. 141. The moving part, the armature, consists of a cylinder of soft iron which rotates between the poles of a strong electro-magnet. Mounted on the armature in a slot is a coil of wire. There is a ring at one end of the armature which is divided into two halves, or segments, insulated from each other. This split ring is called the commutator. The leads from the armature coil are connected one to each segment and the current passes to and from the armature coil by means of two brushes pressing on the commutator. These are usually of carbon but are shown as strips of metal in the sketch.

When the armature is in the position shown in the figure a current passing from one brush to the other through the armature coil

converts the armature into a magnet with the poles as shown. The polarity is simply obtained by the right-hand rule. There is repulsion between the upper pole of the armature (a north pole) and the north pole of the field magnet and a corresponding attraction between it and the south pole of the field magnet. The armature under the action of these forces (and the corresponding forces due to the south pole of the armature) consequently rotates in a clockwise direction.

By using the commutator to reverse the current through the coil at each half turn, the rotation is maintained by forces always acting in the same direction.

Galvanometers.—Most of these instruments used for measuring current depend on its magnetic effect. Fig. 142 shows the construction of a moving coil instrument for measuring current. A coil is pivoted on jewelled bearings and turns between the poles of a permanent magnet, being normally held to its zero position by two spiral springs which also act as leads to the coil. When a current flows through it the coil is converted into an electromagnet, as shown in the figure. The repulsion of like poles of the coil and of the permanent magnet, and the attraction of the unlike poles causes the coil to turn. In this respect as well as in the general arrangement of the coil and the magnet this instrument closely resembles the electric motor. The coil comes to rest with the pointer at a reading on the scale which depends on the current flowing and the control exerted by the springs.

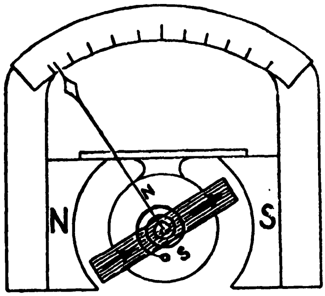


FIG. 142

Electricity and Chemical Change.—When an electric current is passed through acidulated water the water is decomposed into hydrogen and oxygen (page 65). The hydrogen is evolved and gathers at that immersed plate which is joined to the negative pole and which is called the cathode, while the oxygen is evolved and gathers at the other immersed plate which is joined to the positive pole and is called the anode. This decomposition of a substance by electricity is called electrolysis, and solutions which can be so decomposed are known as electrolytes.

Solutions in water of acids, bases and salts can be electrolysed. The hydrogen of the acid and the metal of the base or salt always

collect at the cathode, while the non-metallic part of the substance collects at the anode. In many cases the metal or the non-metallic part undergo further chemical change, maybe with the water or the cathode, or anode, or with the solution. Thus when a solution of common salt ($NaCl$) is electrolysed sodium is formed at the cathode and chlorine at the anode. If the anode is made of carbon the chlorine does not react with it and is given off, but the sodium reacts with the water, forming sodium hydroxide and hydrogen.

The process of electrolysis is used in electroplating, thus in copper plating the article is joined to the negative pole of the battery and so is made the cathode, while the anode is a piece of pure copper. Both are immersed in a solution of copper sulphate. When the current flows the copper sulphate is decomposed. The copper is deposited in an even layer on the cathode. The sulphate part of the salt which goes to the anode combines with as much copper as it formerly was combined with, so re-forming as much copper sulphate as was decomposed. In effect therefore the process consists of transferring copper from the anode to the cathode through the medium of a salt of copper. Silver plating is done similarly, using a silver anode and a solution of a silver salt. Other metals used in electroplating are nickel and chromium.

Electrical Measurements.—The flow of electricity in a circuit, whether from a battery or from the mains supply, is comparable in many of its characteristics with the flow of water in a pipe. The pump in the water " circuit " shown in Fig. 143 exerts a pressure on the water and forces it along the pipes. The battery forces the electric current through the circuit and the pressure it exerts is

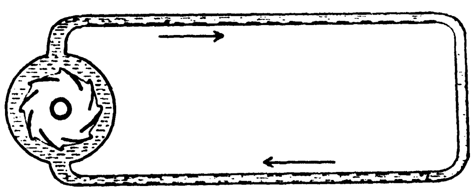


FIG. 143

known as its " electromotive force " (E.M.F.). It is measured in volts and hence the term voltage is frequently used instead of the longer name. When the pressure exerted by the water pump increases, the rate of flow of water increases. Similarly when the voltage is increased the rate of flow of electricity in the circuit

is also increased. A one-cell accumulator has an E.M.F. of two volts, and when two cells are connected together to form a battery —the positive pole of one being joined to the negative of the other —the total voltage is four volts. Many cells can all be connected in a similar way and the total voltage obtainable is the sum of the individual voltages of each cell. Cells connected in this way are said to be "in series."

Most electrical appliances, such as lamps, heaters, etc., are made to suit a specified voltage and should only be used in circuits of correct voltage. For example, the type of bulb made for a flash-lamp with a three-volt battery will fuse if used with a four-and-a-half volt battery, while a bulb suitable for this latter voltage gives only a faint light when used with a three-volt battery.

The rate of flow of the water in the circuit (Fig. 143) could be measured by finding the quantity of water (e.g. in cubic feet) flowing through the pipe each second. Similarly, the rate of flow of electricity in a circuit is measured from the quantity flowing through it in one second. The unit of quantity of electricity is the coulomb and the current is said to be one ampere when one coulomb of electricity flows through the circuit in one second.

Electric currents are measured by instruments called ammeters. A moving coil galvanometer (page 148), is one type of instrument used. It is calibrated in amperes and usually has a low resistance, or shunt, across its terminals to by-pass most of the current, otherwise it would be too sensitive to use in most circuits.

Ohm's Law.—The diagram, Fig. 144, shows a battery of accumulators, an ammeter (A) and a coil which offers a resistance to the passage of the current. The electric pressure, that is the voltage, of the battery forces the current through the circuit and the current flowing is measured by the ammeter. When the voltage is doubled (by using two similar cells in series instead of one) the current flowing is found to be twice its former value and when additional cells are added in this way it is found that the currents flowing are proportional to the voltages. Thus the ratio of the current (denoted by C) to the voltage (denoted by E) is constant. This constant expresses the value of the opposition set up by the circuit to the passage of electricity. This opposition is called the resistance of the circuit and is denoted by the letter R.

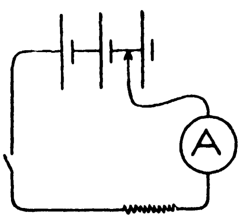


FIG. 144

$$\text{Thus } \frac{\text{Voltage}}{\text{Current}} = \text{Resistance; or } \frac{E}{C} = R.$$

By arranging the equation:

$$C = \frac{E}{R} \text{ and } E = CR.$$

When one volt produces a current of one ampere the resistance is one unit of resistance. This unit of resistance is called the ohm.

From the relation $C = \frac{E}{R}$ it will be seen that the current can be changed either by changing the voltage, as mentioned previously, or by keeping the voltage constant and changing the resistance. A useful way of varying the resistance, and hence the current, is by means of a rheostat (Fig. 145). This consists of a coil of wire of relatively high resistance, one end of which is connected to a

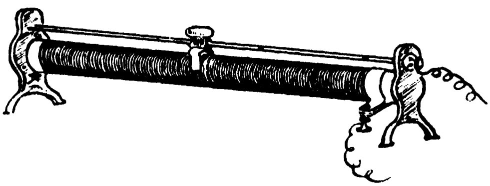


FIG. 145

terminal. The other connection is made by a sliding contact so that varying lengths of wire can be included in the circuit.

The longer the length of wire carrying a current the greater is the resistance. The resistance also depends on the thickness of the wire, being greater for thin wires, and it also depends on the kind of metal used. Wires of certain alloys, e.g. manganin, have a much higher resistance than copper. The resistance of any conductor can be expressed in ohms and the resistance of a circuit can be found by taking the sum of the resistance of each separate part of the circuit.

Power.—The power which is needed to maintain a flow of water by means of a pump depends not only on the pressure needed to force the water through the pipes but also on the rate of flow. Similarly the power supplied by electricity depends on the pressure or voltage of the supply and on the current flowing, i.e. the number of amperes. The unit of power, which is called the watt, is chosen

so that the power in watts is the product of the pressure in volts and the current in amperes. Thus:

$$\text{Watts} = \text{Volts} \times \text{Amperes}.$$

Thus the watt is the power supplied when one volt produces a current of one ampere. This unit is a small one and the kilowatt (1,000 watts) is frequently used. The formula may be expressed as follows when P is the power in watts:

$$P = EC, \text{ or } E = \frac{P}{C}, \text{ or } C = \frac{P}{E}.$$

These relations enable one of the quantities to be found when the other two are known.

Example 1: Find the current taken by a 200-volt, 50-watt lamp.

$$C = \frac{P}{E} = \frac{50}{200} = \tfrac{1}{4} \text{ ampere.}$$

Example 2: Find the power used by a heater carrying 4 amperes at 250 volts.

$$P = EC = 250 \times 4 = 1{,}000 \text{ watts} = 1 \text{ kilowatt.}$$

Electrical Energy.—The work done by an electric current, e.g., in lighting, or heating depends not only on the power supplied but also on the time during which the current is passing, just as the work done by an engine depends on the horse-power and the time the engine is running. The product of the power taken from the electricity mains or from batteries, and the time during which it is supplied, is a measure of the electrical energy used. When the power is in kilowatts and the time in hours the energy is given in kilowatt-hours, or Board of Trade units. Thus:

1 unit = 1 kilowatt supplied for 1 hour.

This unit is used all over the world for the measurement and sale of electricity. The number of units is registered on the electricity supply meter and the amount to be paid is calculated from this, knowing the price per unit. Example: Find the cost of working a 500-watt vacuum cleaner for 15 minutes if the cost of electricity is *2d.* per unit.

1,000	watts	for	1 hour	cost	*2d.*
500	,,	,,	,,	,,	*1d.*
500	,,	,,	$\frac{1}{4}$,,	,,	$\frac{1}{4}$*d.*

If the power is not marked on an electrical appliance it can

be found by running it alone from the mains and ascertaining from the meter the number of units used in a given time. The number of units used in one hour gives the power taken. For example, if the number of units used is 0·3 in 15 minutes, the power is

$$\frac{0{\cdot}3 \times 60}{15} = 1{\cdot}2 \text{ kilowatts.}$$

The power taken by an appliance, e.g. a lamp, can also be found by measuring the current taken and the voltage of the supply. This is done by using an ammeter to measure the current and a voltmeter to measure the voltage. Fig. 146 shows the circuit with the ammeter in series with the circuit and a voltmeter across the lamp.

$$\text{Power (in watts)} = \text{Amperes} \times \text{volts.}$$

(This is not a suitable method of measurement for class use for the meter connections have to be exposed, but the power taken by a car lamp can be found by this method, using a suitable battery.)

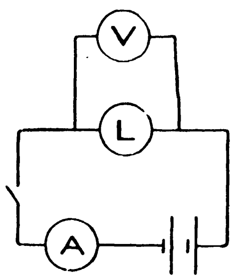


FIG. 146

When a number of different appliances are used the total power taken is the sum of the power taken by each appliance and the current flowing is the sum of the current passing through each. Example: Six 60-watt lamps and a 1-kilowatt heater are in use together. Find the total power required and the current used if the voltage is 230.

$$\text{Power required} = (6 \times 60) + 1{,}000 = 1{,}360 \text{ watts.}$$

$$\text{Current used} = \frac{1{,}360}{230} = 5{\cdot}9 \text{ amperes.}$$

PRODUCTION OF ELECTRICITY

Cells and Batteries.—Volta's cell produced electricity as the result of chemical action, and two modern types of this kind of cell are the Leclanché cell and the dry cell. The Leclanché cell (Fig. 147) has a glass vessel containing a strong solution of ammonium chloride (sal ammoniac). A rod of zinc is placed in this, as shown, and also a porous pot which contains manganese dioxide and powdered carbon, as well as a carbon plate. A terminal is affixed to the plate, the other terminal being the top of the zinc rod. An electric current is produced when the zinc reacts with the sal

ammoniac. Hydrogen as well as other substances are formed. This hydrogen travels towards the carbon plate and, but for the manganese dioxide, would settle on the plate, preventing it from acting properly, and so reducing the flow of electricity. This accumulation of hydrogen on the plate is called polarization. The manganese dioxide, however, prevents this accumulation, since it oxidizes the hydrogen, and manganese dioxide is said to be a depolarizing agent. But the manganese dioxide oxidizes the hydrogen at a slow rate so that when the cell is used continuously for a long time polarization occurs. The Leclanché cell therefore is best used when the current is required for short intervals.

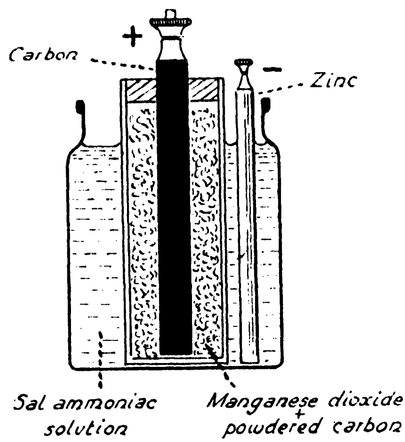


FIG. 147

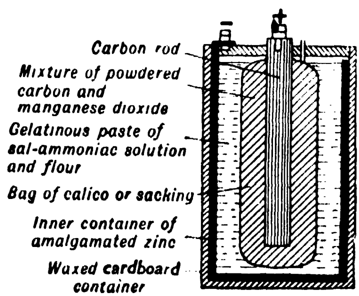


FIG. 148

Dry Cells.—The Leclanché cell is not a convenient one for transporting and is somewhat bulky, but the present day dry cell, Fig. 148, has not these disadvantages. It is really a modification of the Leclanché cell. Instead of the sal ammoniac solution this substance is made into a paste with flour. There is no porous pot, the manganese dioxide and powdered carbon being contained in a calico bag in which is the carbon rod. The case of the cell is made of zinc and this takes the place of the zinc rod. Dry cells are made in batteries containing varying numbers of cells connected in series and are used for purposes either where the current is small, as in wireless high-tension batteries of 60 to 120 volts, or for intermittent work as for bells and flash-lamps. The voltage of a Leclanché or dry cell is usually about 1·5 volts but falls appreciably some time before the cell is completely run down.

The Accumulator.—There are a number of lead plates in the common type of accumulator, each of which has a "grid" surface (Fig. 149). In a freshly charged accumulator the spaces or pockets of the grids of every other plate are filled with spongy lead—these are the negative plates. The alternate plates are filled with lead dioxide which acts as a depolarising agent and is chocolate coloured; they are the positive plates. All the positive plates are connected together, and finally to the positive terminal, all the negative plates being similarly connected to each other and to the negative, terminal. The plates are immersed in dilute sulphuric acid of a definite strength, such a solution having a specific gravity of 1·25. When the current is taken from the accumulator, chemical changes take place as a result of which the lead on the negative plates and the lead dioxide on the positive plates both tend to become converted into lead sulphate. Since the sulphate part comes from the acid the solution becomes weaker, until when the accumulator has almost run down or become discharged, the specific gravity of the acid has fallen to 1·18. Hence one method of finding the state of discharge is to measure the specific gravity of the acid by a hydrometer. The accumulator is re-charged by connecting it to a source of direct current in such a way that the current is sent into the accumulator in the opposite direction to that it takes when discharging. The electric current electrolyses the dilute acid and hydrogen and oxygen are formed (page 65). The hydrogen reacts with the lead sulphate, converting it into lead on the negative plate and the oxygen produces lead dioxide on the positive plate. The hydrogen combines with the sulphate radical, reforming as much sulphuric acid as was decomposed during the discharge of the cell, so that the sulphuric acid has again a specific gravity of 1·25.

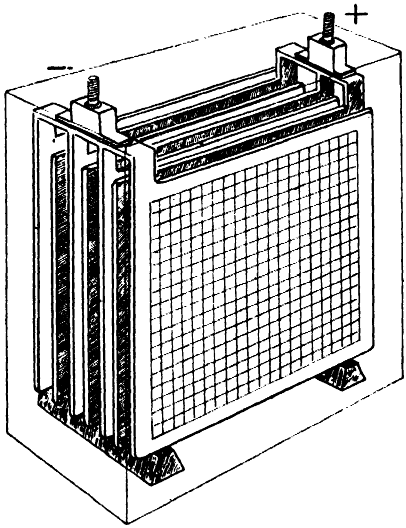
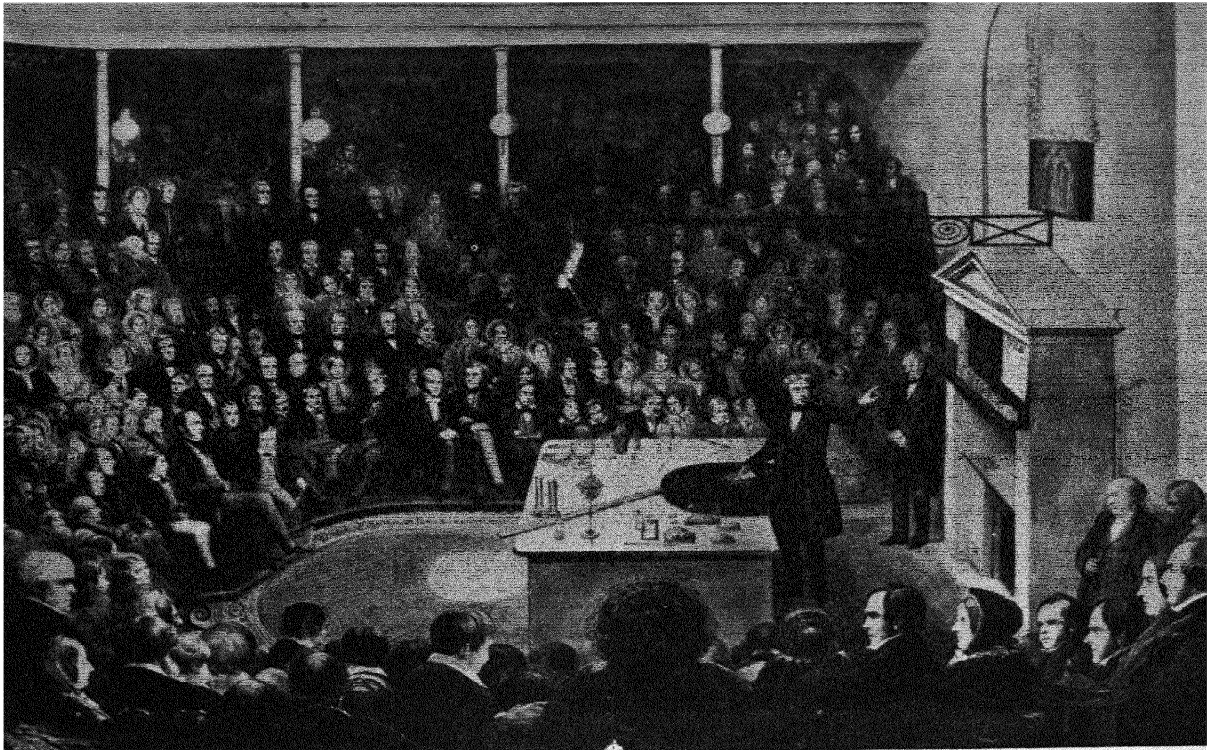


Fig. 149

Each cell of an accumulator has an E.M.F. of two volts. Its



Courtesy of Rischgitz Art Studios

FIG. 10

Faraday Lecturing at the Royal Institute. (By A. Blaikley)
(The Prince Consort and Prince Edward are in the Audience)

capacity is given in ampere-hours. Thus if a charged accumulator at a discharge rate of 5 amps gives out this current for 12 hours before it is fully discharged its capacity is $5 \times 12 = 60$ amp. hours. The capacity depends on the weight of the materials acted upon during the discharge and so on the number and size of the plates. The E.M.F. of the cell, however, does not depend on its size.

Dynamos.—A small direct-current motor worked from batteries of accumulators may easily be made to act as a dynamo, by driving the armature round in the same direction as it was driven as a motor, but at a somewhat higher speed. It will then charge the battery instead of taking current from it. A machine worked as both a dynamo and motor is still used in some cars. It acts as a motor when it takes current from the car battery and turns the engine in starting it up. Afterwards it is driven by the engine and, acting as a dynamo, is used to charge the battery.

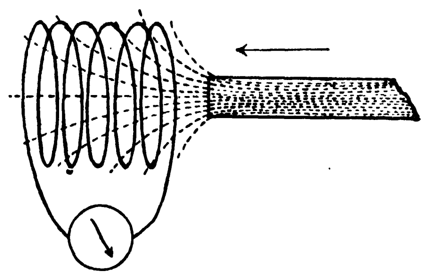


FIG. 151

The current generated by the dynamo is produced by the rotation of the armature coil (or coils) in the negative field between the poles of the field magnet. This effect depends upon a principle discovered by Michael Faraday and it can be illustrated by pushing a magnet into a coil connected to a galvanometer (Fig. 151). As the movement takes place a current flows. A current is obtained, but in the opposite direction when the magnet is removed. When the magnet is turned end to end and the experiment repeated the currents are both in the opposite directions to those previously obtained. The currents flowing are called induced currents and are produced as the lines from the magnet enter or leave the coil, so being cut through by the turns. The working of a dynamo may better be seen by considering a coil rotating in a magnetic field.

Coil rotating in a Magnetic Field.—The current observed in a coil as it moves steadily round between the poles of a magnet may be followed from Fig. 152. A galvanometer completes the circuit and is shown in each diagram but without the connections from it to the coil. When the coil is in the position (*a*) there is no current through the circuit as the *sides* of the coil AB are moving past the

lines and not cutting through them. The current rises as the turn proceeds and reaches its highest value in the position (*b*) when the lines are being cut at the fastest rate. The current then falls and there is no current when in position (*c*) for there are again no lines being cut. The conditions are the same during the second half turn as during the first, except that the coil has reversed its

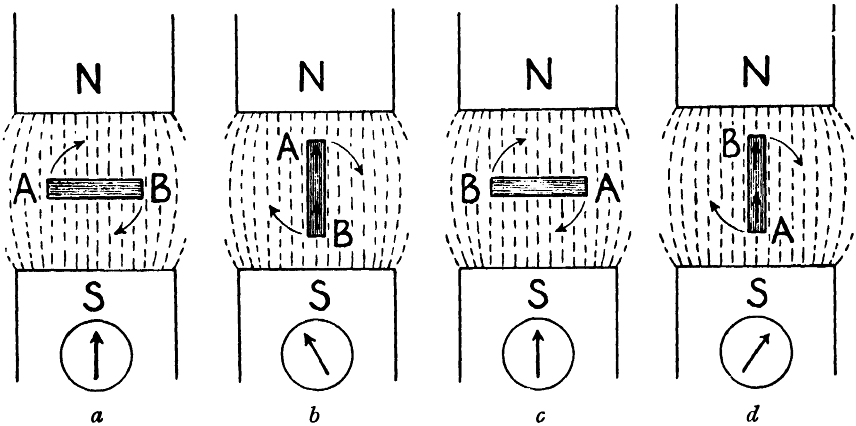


FIG. 152

position with respect to the field and the current consequently increases to a maximum as before, only in the reverse direction. It reaches the maximum when in the position (*d*) and falls to zero as it completes the turn. In a complete revolution the current passes through a complete series of changes. It is known as an alternating current.

Alternators.—A practical form of alternating current generator or alternator needs a method of taking off the current from the ends of the rotating coil. This is arranged by means of slip rings (Fig. 153) on the axis of the armature which carries the coil. The ends of the coil P and Q are connected to the rings and make connection with the external circuit by means of brushes, B_1 and B_2 which maintain contact as the coil rotates. Modern alternators, however, have fixed coils on the outside and a rotating system of electro-magnets forming the armature.

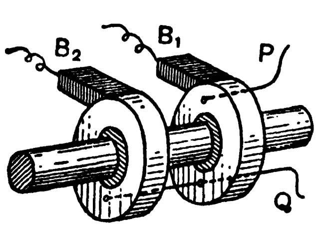


FIG. 153

A small direct current dynamo is used to supply the field magnets with current. Alternators in use at power stations are usually driven by steam turbines and supply as much as 30,000 kilowatts of electrical power at a pressure of 6,600 volts.

The Transformer (Fig. 154).—A transformer is used to change the voltage of an alternating current supply of electricity. It consists of two coils, the primary and the secondary wound on the same soft iron core which is built up in sheets or laminations. Alternating currents passing through the primary coil magnetize the iron, so producing changing magnetic lines through the secondary coil. Induced alternating currents then flow in the coil just as they would if a magnet moved rapidly backwards and forwards through it. A transformer is used for changing the voltage of the supply from the power station to a high value for sending the power along transmission lines. A transformer of this kind produces a step up in voltage depending on the numbers of turns in the two windings. For instance, if the secondary has 20 times as many turns as the primary the voltage obtained from the transformer is 20 times that supplied to it. Transformers are also used for stepping down voltages by using more turns in the primary than in the secondary. Besides their use in the distribution of electricity transformers are employed in many applications of electricity where the main A.C. supply voltage is not suitable. In a wireless set, for example, the mains transformer supplies current at several different voltages for use in the receiver.

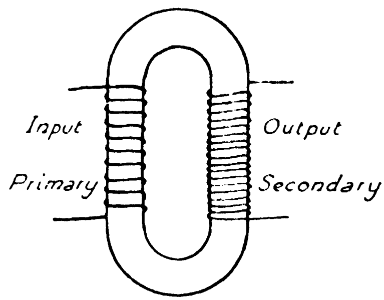


FIG. 154

A transformer cannot give out more electrical power than it takes in. When the pressure it produces is higher than that supplied to it the current it gives out is less than that which is supplied to it, and vice versa.

CHAPTER XV

WATER: SOLUTIONS

WATER is of great importance to all plant and animal life, chiefly because it dissolves many substances—gases and liquids as well as solids—but owing to this property pure natural water is rarely found. Impure water, however, can easily be purified. When it is heated it gives off steam, which is pure water vapour. Solid impurities remain in the vessel containing the impure water; most gaseous impurities are expelled before an appreciable amount of steam has been given off and liquid impurities boil at a temperature different from that at which water boils. So to obtain pure from impure water the latter is heated and the steam given off at 100° C. is condensed and the water collected, allowing the steam which is given off at first to escape.

The Distillation of Water.—Impure water is put in a round-bottomed flask and heated and the steam is passed through a

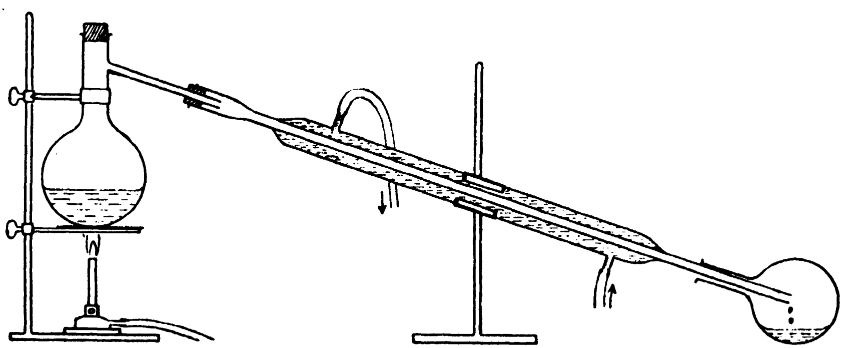


FIG. 155

Liebig's Condenser (Fig. 155). The steam passes into the central tube of the condenser, which is surrounded by running cold water and is there condensed, i.e. turned back into water which trickles

into the receiver. The water which is at first collected might contain some of the dissolved gases which were driven off at first and which then dissolve in it. The purest water is that which is collected after distillation has proceeded for a short time.

Dissolved Air in Rain Water.—Rain, in falling through the air, dissolves some of the gases of the air—oxygen, nitrogen, and carbon dioxide. These gases are driven out when the water is heated. To show this a flask (Fig. 156) is completely filled with rain-water, and the tube put flush with the bottom side of the cork. The delivery tube is also filled with rain-water and carefully put in the pneumatic trough under a collecting tube (about a metre long) full of water. It is important that each vessel and tube is completely full of water so that no free air is present in the apparatus.

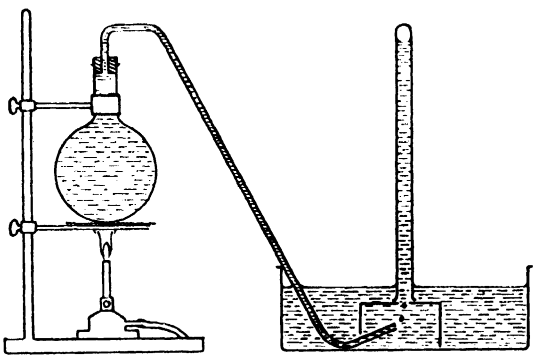


FIG. 156

The flask is then heated and the dissolved air is driven out and collected in the tube. When this is analysed, e.g. by burning phosphorus in it (as on page 52), it is found that one-third of the "dissolved air" is oxygen. Hence the air which has been dissolved in water is richer in oxygen than ordinary air (which contains only one-fifth of oxygen). This is of great importance to those plants and animals which live in water and which depend on the dissolved air for their oxygen supply.

Solutions.—Powdered sodium carbonate is soluble in water; that is, when a little of it is added to cold water and stirred the powder disappears, or dissolves. When more powder is added little by little and the water stirred, in time a point is reached when no more will dissolve. The solution which is then obtained is called a saturated aqueous solution. But if the water is then

heated it will dissolve more of the powder. The weight of powder which dissolves depends on the weight of water used and the temperature. Generally speaking, the hotter the water the greater is the weight of solid which will dissolve in it. A boiling saturated solution contains a much greater weight of solid than does an equal volume of a cold saturated solution, and if a boiling saturated solution is put on one side to cool slowly the " extra weight " of the solid is deposited as the solution cools.

A hot saturated solution of sodium carbonate on cooling deposits the solid in the form of crystals. These crystals can be filtered off from the liquid and dried between filter paper. They have a definite shape or form. This experiment can be repeated with numerous other soluble substances and many different kinds of crystals obtained, some of which are very common substances. Thus the crystals of sodium carbonate are washing soda crystals ; and crystals formed from a hot saturated solution of magnesium sulphate are those of Epsom Salts.

Water of Crystallization.—When dry crystals of washing soda are heated in a test-tube, a vapour is given off ; when condensed this gives a liquid which can be shown to be water (by the anhydrous copper sulphate test, page 63). This water is known as water of crystallization and crystals which contain such water are known as hydrated crystals. Not every substance, however, forms hydrated crystals. Thus when a hot saturated solution of potassium chlorate is cooled, crystals containing no water of crystallization are formed. Such crystals are known as anhydrous crystals, i.e. crystals without water.

Efflorescence.—A few compounds which form hydrated crystals lose some of the water of crystallization on exposure to air and are called " efflorescent substances." A very common efflorescent substance is washing soda, crystals of which consist of 106 parts by weight of sodium carbonate, combined with 180 parts by weight of water (so when purchasing washing soda more water is bought than the useful sodium carbonate). When washing soda is left exposed to the air, say in the kitchen at home, it effloresces, i.e. loses some of its water of crystallization, and a dry powder covers the crystals. (This is readily noticed on examining some household supplies of the substance.)

Deliquescence.—On the other hand, certain substances on exposure to air will combine with some of the moisture in the air and become damp. These are known as hygroscopic substances.

Others will even attract enough moisture to form a solution, and are known as deliquescent substances. A common one in the laboratory is fused calcium chloride and it is frequently used to dry gases because when gases containing water vapour are passed through **U**-tubes containing it, the water vapour combines with the chloride (see Fig. 64). Ordinary common table salt—sodium chloride—contains a deliquescent substance as an impurity. This impurity attracts some of the water vapour of the air and the salt becomes damp and sometimes "cakes."

Evaporation.—When a solution is heated until all water is driven off, a solid remains which generally is not crystalline but powdered. This process is known as evaporation to dryness. All the solid which was dissolved in the water can be recovered in this way unless it is decomposed by heat.

Aqueous Solutions.—Aqueous solutions, i.e. solutions in water, are of very great importance not merely to the chemist and manufacturer but to all plants and animals. One reason is that many chemical reactions which readily take place when solutions of two solids are added together will not do so if the solid substances themselves are mixed. A solution is, moreover, a convenient agent for carrying a substance from one place to another. For example, there are many substances in the soil which the living plant needs. These have to become dissolved in the water in the soil before they can pass into the roots of the plant (page 289). Again, animals eat many solids which are insoluble. Before these can be of use to the animals they must be converted into soluble substances and this is done during the process of digestion (page 268). In the plant the solution containing the soluble substances is transported by the sap to the various parts of the plants; in the animal it is carried round the body by the blood-stream.

Diffusion.—There are many coloured gases which are heavier than air, such as bromine, which is brown, and five-and-a-half times heavier than air. A stone sinks when thrown into water because it is denser than water, and if the force of gravity (page 19) alone were acting on bromine we should expect bromine gas to sink in air, that is when a gas jar of bromine was put upside down on top of a jar of air, we should expect the bromine to fall into the bottom jar. Actually some of it does, but not all, some of it remaining in the upper jar. But a more striking experiment is one in which a jar of bromine is stood upright and a jar of air inverted on top of it (Fig. 157). In a few minutes the brown colour of the bromine is

clearly seen in the top jar. Some of the molecules of the bromine have actually travelled against the direction of the force of gravity. It will be remembered that molecules of gases are travelling at great speeds in all directions. If the bottom jar was at first full of midges, some of them would soon fly into the top jar. In a similar way the bromine molecules soon move into the top jar. This property of a gas of spreading its molecules into the space occupied by another gas (air) is known as diffusion. Experiments show that a light gas diffuses more quickly than a heavy one.

The presence of a gas, even when it is produced some distance away, can often be detected by its smell for the gas diffuses through the air. Many liquids evaporate at ordinary temperatures and are smelled because their vapours diffuse through the air—e.g. scents and liquid ammonia.

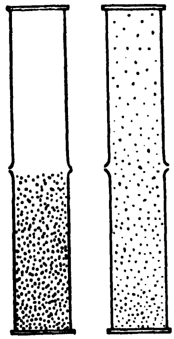
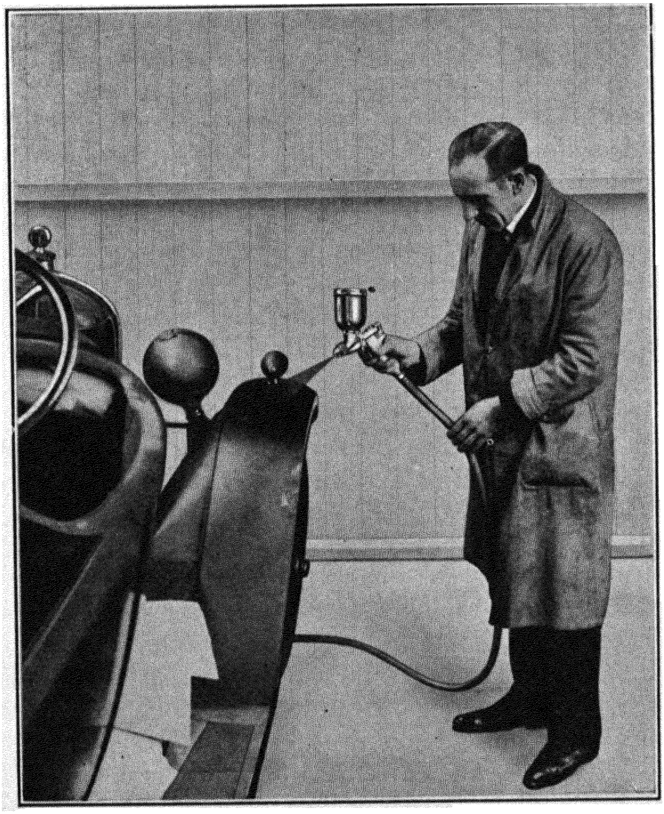


FIG. 157

Diffusion also takes place in liquids. A strong solution of blue copper sulphate is denser than water. When it is poured gently down a thistle funnel which touches the bottom of a beaker of water it forms a blue layer at the bottom of the beaker. If the beaker is left undisturbed for some time all the water in the beaker gradually becomes blue. The molecules of the copper sulphate travel upwards and mix intimately with the molecules of water. This mixing is hastened by stirring the liquid, the stirring distributing the molecules very quickly. An aqueous solution can be regarded as an intimate mixture of water molecules with the molecules of the dissolved substance.

Solvents other than Water.—Water does not dissolve everything, but many substances which are insoluble in it dissolve in other liquids. For example, wax or oil although insoluble in water dissolve in petrol, benzene and other "organic" liquids. Thus many solutions do not contain water and a few of these of everyday importance will be considered. Cellulose lacquer is nowadays a fairly common substance. It is a solution of cellulose in such a liquid as amyl acetate. This liquid evaporates when exposed to the air, no heating being necessary, and when the lacquer is sprayed on a surface a thin coating of cellulose is left after the liquid has evaporated. A modern method of lacquering is shown in Fig. 158. The solution of cellulose is being sprayed on to the wings of a

motor-car ; the liquid evaporates, leaving a coating of the cellulose. French polish is a solution of shellac in methylated spirits. This is brushed or sprayed on to the wood. The methylated spirits evaporate, leaving a thin, smooth and shining coating of shellac. The ordinary rubber solution used to mend a puncture is a solution



Courtesy of Aerograph Co., Ltd.

FIG. 158
Cellulose Spraying

of rubber in petrol. The solution is put on the patch and the petrol allowed to evaporate until there is a thin film of "tacky" rubber on the patch. It is put over the puncture and the rest of the petrol soon evaporates, leaving the rubber of the solution adhering both to the patch and to the tyre, so sticking them together.

Dry Cleaning.—Grease, wax and other similar substances are soluble in petrol or benzene and these two liquids can be used to

dissolve out the grease or wax on clothes. Petrol and benzene are, however, highly inflammable liquids and must be used with great care. Instead of these many " dry cleaners " use a liquid called carbon tetrachloride which, besides dissolving grease and wax, is non-inflammable. The soiled material is first treated with the liquid and the solution of grease and oil is drained off. It is then evaporated and the vapour of the solvent is condensed and so re-obtained in a pure state. The material is still damp with carbon tetrachloride so it is put in a warm chamber and the liquid evaporates, leaving the material dry. The vapour is condensed and the liquid used again.

Colloidal Solutions and Emulsions.—It is frequently desirable to get into " liquid " form an insoluble substance, particularly in the preparation of some of the newer kinds of medicine. This is now done by making what are known as colloidal solutions. During the preparation of these solutions the solid substance is scattered throughout the solvent in tiny solid particles either by a mechanical or else a chemical process. These extremely tiny particles of the solid are too small to be seen individually by the naked eye or even under a microscope but are very much larger than molecules. They are, however, still sufficiently small not to have lost their power of movement and move about in the liquid like a swarm of midges in the sunlight. They would, however, coalesce and settle to the bottom but for the addition of certain substances which prevent this from happening. There are numerous colloidal solutions of commercial importance, a common one being colloidal graphite. Graphite is a good solid lubricant and when it is dispersed or scattered throughout a lubricating oil a much better lubricant called colloidal graphite is obtained.

In another type of colloidal solution a liquid is dispersed instead of a solid and the product is called an emulsion. Oil does not dissolve in water, but when a relatively small volume of it is vigorously shaken with water it forms very small globules (or drops) which remain suspended for a long time, particularly if certain substances are added to make the suspension more or less permanent. There are many natural emulsions, milk being one. It is composed largely of butter fat which is kept in suspension in the solution by other substances in the milk. A common domestic emulsion is salad dressing, one kind of which is a suspension of olive oil in vinegar and milk (or cream) to which salt, mustard and the yolk of eggs have been added.

Separation.—An insoluble substance can be separated from a soluble substance with which it is mixed. If, for example, a mixture of sugar (soluble) and sand (insoluble) is boiled with sufficient water the sugar dissolves. The mixture is then filtered and the sand remains in the filter paper and is known as "the residue" while the sugar solution passes through and is known as the "filtrate." A familiar example of a different method of separation (to girls at any rate) occurs during clarifying of fats. After fat has been used for some time in cooking it contains many small pieces of the food which has been cooked in it. The used fat is boiled with water and some of the impurities in the fat such as salt dissolve in the water. The fat melts to form a liquid which is less dense than water and so floats. Most of the small bits of food, e.g. fried potatoes, are denser than water and sink. When all is cool, the fat solidifies on the surface of the water and can be taken off purified.

CHAPTER XVI

ACIDS, BASES AND SALTS

THERE are many substances which have several properties in common; they have a sour taste, turn blue litmus red, and react with certain substances to produce a gas, the process being accompanied by a faint sizzling noise and the appearance of bubbles in the liquid. These substances are known as acids. Some of them are called vegetable acids, the name indicating their origin, e.g. citric acid is found in lemon juice, malic acid is contained in sour apples, tartaric acid is produced during the fermentation of wine and vinegar is formed when wines go sour (acetic acid can be obtained from vinegar). As a general rule vegetable acids such as these are not easily prepared in the laboratory. Another class of acids known as mineral acids are obtained from mineral substances, and three such acids, sulphuric acid, hydrochloric acid and nitric acid, have been known for many centuries, although not by their present names.

Sulphuric Acid (commonly known as Oil of Vitriol).—This acid is manufactured by dissolving one of the oxides of sulphur in water. Sulphur forms two oxides: sulphur dioxide, which is prepared by burning sulphur in air or in oxygen, and sulphur trioxide. Although sulphur trioxide is richer in oxygen it cannot be formed simply by burning sulphur in air or in oxygen no matter how much oxygen is present. It is prepared by passing sulphur dioxide mixed with oxygen over a heated catalyst such as platinized asbestos, thus:

$$\text{Sulphur Dioxide} + \text{Oxygen} \xrightarrow[\text{asbestos}]{\text{platinized}} \text{Sulphur Trioxide.}$$

$$2SO_2 + O_2 \longrightarrow 2SO_3$$

As in the case of other catalysts (page 54) the platinized asbestos is not used up. The apparatus used in the laboratory is shown in Fig. 159. Dry sulphur dioxide is passed in at one tube and dry oxygen at the other. They mix and pass through the hot platinized asbestos and combine to form gaseous sulphur trioxide. This gas

forms silky needles when cooled and these are collected in the receiving flask, which is placed in a freezing mixture. Sulphur trioxide is manufactured in a similar way, the dioxide and oxygen being passed into a tower containing the heated catalyst. When dissolved in water sulphur trioxide yields sulphuric acid, thus:

Sulphur Trioxide + Water = Sulphuric acid.

$$SO_3 + H_2O = H_2SO_4$$

Concentrated sulphuric acid boils at 320° C. and can be heated gently without much of it turning into a gas. It is said to be non-volatile (volo = to fly). The two other commercial mineral acids are volatile, so that when a mixture of sulphuric and hydrochloric acids is heated gently the hydrochloric acid comes off as a gas, but the sulphuric acid does not. Nitric acid behaves in the same

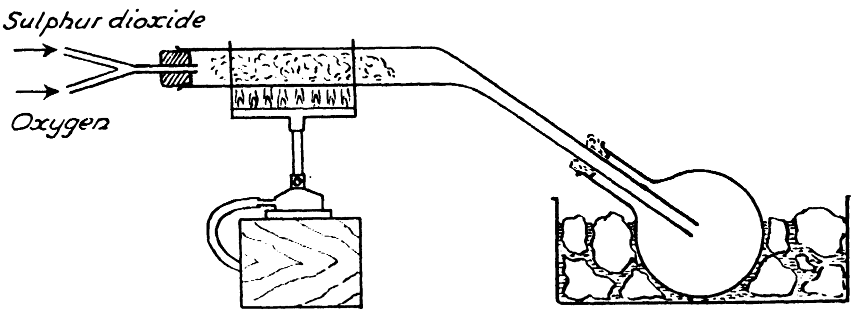


FIG. 159

way. This property accounts largely for the use of concentrated sulphuric acid for the preparation of the other two acids by similar methods. In each case concentrated sulphuric acid acts on a salt, a chloride for hydrochloric acid and a nitrate for nitric acid. Double decomposition takes place with the formation of a sulphate and either hydrochloric or nitric acid. Usually the cheapest salts are used, i.e. sodium chloride (common salt) and sodium nitrate (Chile Saltpetre). The similarity is brought out by the equations below.

Sodium Chloride + Sulphuric Acid
= Sodium Sulphate + Hydrochloric Acid.

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$$

Sodium Nitrate + Sulphuric Acid
= Sodium Sulphate + Nitric Acid.

$$2NaNO_3 + H_2SO_4 = Na_2SO_4 + 2HNO_3$$

Hydrochloric Acid.—Common salt is put in the round-bottomed flask (Fig. 160) and sulphuric acid, diluted with an equal volume of water, is poured down the thistle funnel. Hydrogen chloride gas is given off which dissolves in the water forming a solution of hydrochloric acid. The gas is very soluble and the funnel is used to prevent the water from rising up the tube and so entering the hot flask. Water rises up the funnel a little way, but as soon as the level of the water in the beaker falls below the surface of the funnel, the water drops back.

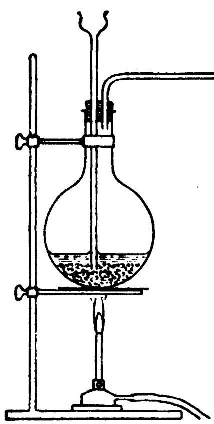


FIG. 160

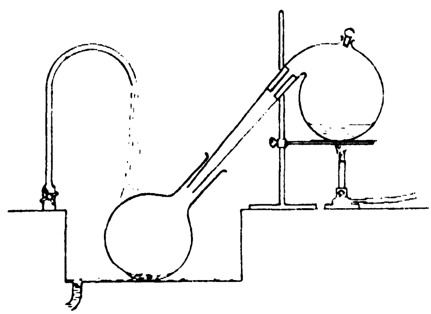


FIG. 161

Nitric Acid.—This substance attacks cork and rubber so that an all glass apparatus (Fig. 161) is used. Sodium nitrate is put in the retort and sulphuric acid, diluted as above with water, is added. The retort is heated and fumes of nitric acid mixed with water vapour are given off. These enter the cooled receiver and are condensed to liquid nitric acid.

Hydrochloric acid is sometimes known as muriatic acid, the name indicating that it is prepared from salt (murium = salt) ; nitric acid is a strong corrosive acid and is sometimes known as *aqua fortis* (strong water).

Properties of Acids.—The three common mineral acids are frequently used in the laboratory either "concentrated" or "dilute." A dilute acid, as the name signifies, is acid mixed with a relatively large volume of water. Concentrated acids react very vigorously with many substances ; for example, concentrated sulphuric acid attacks flesh and if some is spilled, say, on the hand,

it might cause a serious burn; it also chars wood and sugar. All these acids burn holes in cloth and when concentrated must be handled very cautiously.

Properties of Acids.—

1. They have a sour taste. (Caution—only one or two drops of a concentrated solution should be put in a 250 c.c. beaker of water when the taste is being demonstrated.)
2. They turn litmus red.
3. Dilute hydrochloric acid or sulphuric acid (but *not* nitric acid) yield hydrogen with the metals zinc, or iron (but not copper).
4. An effervescence takes place and carbon dioxide is given off when acids react with carbonates.

Concentrated and dilute acids do not always react with other substances in the same way, e.g. concentrated sulphuric acid does not give hydrogen with zinc and the other metals.

Alkalies.—Acids turn litmus red whereas substances of another class, alkalies (page 55), turn the litmus blue. Thus, when a acid is added, drop by drop, to an alkaline solution containing blue litmus, for a time no colour change takes place. But when there are equivalent amounts of acid and alkali present the litmus is neither red nor blue, but intermediate or neutral in colour. Such an addition of acid to alkali results in neutralization and is done as follows. By means of a pipette exactly 25 c.c. of bench sodium hydroxide are transferred to a conical flask placed over a white tile and two or three drops of litmus solution added. Dilute hydrochloric acid is added, drop by drop, from a burette, and the contents of the flask are stirred until the litmus turns purple. The volume of acid required to do this is recorded. The flask now contains the "product of neutralization" contaminated with litmus, which has now served its purpose of indicating the volume of dilute acid required to neutralize 25 c.c. of the solution of sodium hydroxide. (Litmus is called an indicator.) Hence another 25 c.c. of bench sodium hydroxide is put in an evaporating basin and the volume of acid required to neutralize it is added. The solution is evaporated to dryness over a bunsen-burner and a white solid, which has a salty taste, is left. This substance is common salt, i.e. sodium chloride.

The experiment can be repeated using other alkalies and other acids and in every case a solid substance is left. The substance left is always called a salt; a salt being the product of neutralization.

Only the oxides of a few metals are soluble to any great extent in

water, e.g. the oxides of sodium, potassium and calcium. But oxides of most metals will neutralize acids, forming salts. Thus copper oxide can be added to dilute sulphuric acid until no more will dissolve and there is a slight excess of oxide. All the acid has then been neutralized and the excess of oxide is filtered off. The solution is evaporated until a drop of it, when withdrawn on the end of a glass rod, forms crystals. The liquid is then put on one side to cool. Blue crystals appear and they can be filtered off and dried between filter papers. The metallic oxide, copper oxide, has neutralized the acid, forming a salt known as copper sulphate. The only other product of the reaction is water.

Bases and Alkalies.—Any metallic oxide which reacts with an acid to form a salt and water ONLY is called a base. Common examples are copper oxide, zinc oxide, iron oxide and lead monoxide. Sodium hydroxide is also a base since with an acid it forms a salt and water only. So also are potassium hydroxide, calcium hydroxide and ammonium hydroxide. But these three hydroxides are soluble in water and differ in this respect from the oxides named above.

A base is an oxide or hydroxide of a metal which reacts with an acid to form a salt and water *only*. An alkali is a soluble base, a solution of which turns litmus blue.

Salts.—Salts are the product of neutralization and essentially consist of two parts, a metallic part (from the base) and an acidic part. The particular name of each salt indicates both the metal and the acid, thus:

Copper Oxide + Sulphuric Acid = Copper Sulphate + Water.

Zinc Oxide + Nitric Acid = Zinc Nitrate + Water.

Magnesium Oxide + Hydrochloric Acid = Magnesium Chloride + Water.

It was mentioned earlier that when a metal like zinc acts on dilute sulphuric acid the gas hydrogen is evolved. This, and much other evidence, points to the fact that all acids contain hydrogen. The fact that they form salts indicates that they contain another part which is known as the acid radical.

These facts may be summarized:

Sulphuric acid or hydrogen sulphate yields sulphates.

Nitric acid or hydrogen nitrate yields nitrates.

Hydrochloric acid or hydrogen chloride yields chlorides.

Many salts can also be prepared by the action of a metal on an acid (usually the dilute acid). The salt zinc sulphate is made during the preparation of hydrogen. But if it is required relatively pure, excess of zinc should be used. Granulated zinc is added to dilute sulphuric acid until there is no more effervescence, and the excess of metal is filtered off. The solution is heated to crystallization-point and allowed to cool. The white crystals of zinc sulphate can then be filtered off and dried between filter paper. Other examples are:

Zinc chloride from zinc and dilute hydrochloric acid.
Copper nitrate from copper and dilute nitric acid.
Iron sulphate from iron and dilute sulphuric acid.
Lead nitrate from lead and dilute nitric acid.

Another common method of preparing salts is by the process of double decomposition. Solutions of two substances generally react if on exchanging radicals they can produce an insoluble substance. Thus lead sulphate, which is insoluble, can be made by adding a solution of lead nitrate to a solution of sodium sulphate.

Lead Nitrate + Sodium Sulphate = Lead Sulphate + Sodium Nitrate.

$$Pb(NO_3)_2 + Na_2SO_4 = PbSO_4 + 2NaNO_3$$

Similarly:

Zinc Chloride + Sodium Carbonate = Zinc Carbonate + Sodium Chloride.

$$ZnCl_2 + Na_2CO_3 = ZnCO_3 + 2NaCl$$

and

Silver Nitrate + Sodium Chloride = Silver Chloride + Sodium Nitrate.

$$AgNO_3 + NaCl = AgCl + NaNO_3$$

It is, therefore, useful to remember whether a certain substance is soluble. All the common sodium, potassium and ammonium salts are soluble in water. Nitrates of all common metals are soluble as are all chlorides except those of lead, mercury and silver. Many sulphates are soluble, notable exceptions being lead and barium. Only the carbonates of sodium, potassium and ammonium are soluble.

Soap.—This is made by boiling together sodium hydroxide and solid fat, the reaction being similar in some respects to that of the alkali on an acid. Fats may be regarded as compounds of

stearic acid and the substance glycerine. The caustic soda reacts with the acid to form the salt, sodium stearate, which is soap, and glycerine. The process is carried out in large vessels called vats, and common salt is added to the soapy liquor which is obtained after boiling. The salt causes the soap to settle on the top while the glycerine remains in the bottom layer.

$$\text{Fat} + \text{Sodium Hydroxide} = \underset{\text{(Sodium stearate)}}{\text{Soap}} + \text{Glycerine.}$$

CHAPTER XVII

THE CARBONATES

CHALK and limestone are very common substances in many countries and are found in England, in the Downs, the Cotswolds and parts of the Pennines. Each of these substances when strongly heated yields quicklime, which is manufactured in lime-kilns. The older kilns are tall, barrel-shaped towers. Fuel (coal or wood) is first placed on a grate at the bottom of the kiln. A layer of limestone (or chalk) is put on top of the fuel, then more fuel is added, followed by more limestone and so on. The heat of the burning fuel converts the limestone (or chalk) into quicklime which is mixed with the ashes of the fuel. The presence of these ashes in the lime is not a big disadvantage for many purposes, but in the modern kiln no ashes are formed, the limestone (or chalk) being heated by gas.

When a lump of quicklime is placed on a watch-glass and water added very slowly, drop by drop, a hissing sound is at first heard and steam is given off. Soon the lump crumbles to a dry powder. There must have been much heat evolved to turn water into steam, and this heat is one result of the chemical action between water and quicklime. The product of this reaction is called slaked lime, since it is formed by " slaking " the lime, i.e. by adding water.

$$\text{Quick Lime} + \text{Water} = \text{Slaked Lime}$$
$$CaO + H_2O = Ca(OH)_2$$

A solution of slaked lime turns litmus blue and is like the solution made by the addition of calcium to water (page 60). Its chemical name is calcium hydroxide and it is an alkali. Carbon dioxide is an acid gas and since alkalies and acids react to produce salts the two substances, calcium hydroxide and carbon dioxide, react to form a salt known as calcium carbonate.

Calcium carbonate is the white precipitate which is formed at first when carbon dioxide is bubbled into lime-water (page 59). If

the passage of carbon dioxide is continued the white precipitate disappears and a clear solution is left. This clear solution is a solution of another salt, called calcium bicarbonate. Thus :

Slaked Lime + some Carbon Dioxide = Calcium Carbonate (insol.)

$$Ca(OH)_2 + CO_2 = CaCO_3 \downarrow + H_2O$$

Slaked Lime + excess Carbon Dioxide = Calcium Bicarbonate (sol.)

$$Ca(OH)_2 + 2\ CO_2 = Ca(HCO_3)_2$$

When a solution of calcium bicarbonate is heated carbon dioxide is driven off, leaving insoluble calcium carbonate. Thus :

Calcium Bicarbonate = Calcium Carbonate + Carbon Dioxide + Water.

$$Ca(HCO_3)_2 = CaCO_3 \downarrow + CO_2 + H_2O$$

Preparation of Carbon Dioxide.—Chalk, limestone and marble are each different forms of the same chemical substance. This can be shown by heating 100 grams of each, when 56 grams of quicklime and 44 grams of carbon dioxide are formed from each of the three. But the method of obtaining carbon dioxide by heating these substances is not a convenient one and the gas is usually prepared in the laboratory by treating marble with dilute hydrochloric acid.

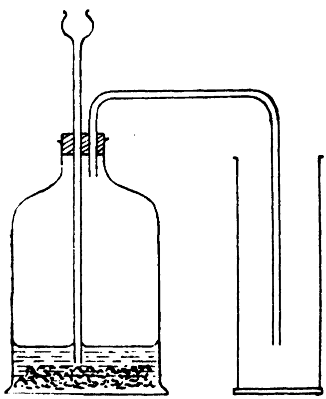


FIG. 162

Pieces of marble are put in the bottle (Fig. 162) and covered with water. Hydrochloric acid is then poured down the thistle funnel and effervescence takes place. The gas, being heavier than air, is collected as shown.

Calcium Carbonate + Hydrochloric Acid = Carbon Dioxide + Calcium Chloride + Water.

$$CaCO_3 + 2HCl = CO_2 + CaCl_2 + H_2O$$

Properties of Carbon Dioxide.—

(*a*) It has no colour or smell and is heavier than air.
(*b*) It is soluble in water producing a weak acid solution.
(*c*) It does not burn or allow other substances to burn in it (with few exceptions).

(*d*) It turns lime-water milky.

(*e*) It forms salts with alkalies. Thus with sodium hydroxide it forms sodium carbonate and so can be absorbed by a solution of sodium hydroxide.

Carbon dioxide dissolves in water, producing a solution with a " sharp " taste. More of it dissolves in a certain volume of water at high pressures than at low. " Soda-water " is a solution of carbon dioxide in water made by dissolving the gas at a greater pressure than atmospheric. " Mineral waters " are solutions of fruit juices in which the gas has been dissolved under high pressure When a bottle is opened the pressure becomes normal and carbon dioxide comes out of solution, causing the effervescence which produces an " aerated " liquid.

Carbon dioxide does not support combustion. It is produced in certain types of fire-extinguishers. One such type (Fig. 163) contains an acid, usually in a small glass bottle, and a solution of sodium bicarbonate. The acid is released in this type by turning the extinguisher upside down. (In the " plunger type " it is released by striking the knob, which breaks the bottle containing the acid.) As soon as the acid and carbonate react carbon dioxide mixed with the liquid rushes out of the nozzle.

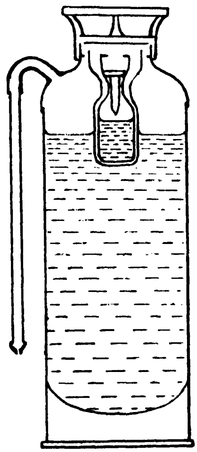


FIG. 163

The importance of carbon dioxide to plants is mentioned elsewhere (page 292) also its production in combustion and other methods by which it is given to the air. These may be summarized as follows:

Methods by which Carbon Dioxide is Given to the Air.—

(*a*) By animal and plant respiration (Chapter XXXIII).

(*b*) When fuels burn (Chapter XVIII).

(*c*) In many manufacturing processes, e.g. brewing.

(*d*) As the result of plant decay.

Hard and Soft Water.—The wide distribution of chalk, limestone and marble had interesting consequences. Rain in falling through the air dissolves some carbon dioxide. When this solution falls on limestone or chalk some of the calcium carbonate reacts with the solution of carbon dioxide to form soluble calcium bicarbonate.

Thus:

Calcium Carbonate + Water + Carbon Dioxide = Calcium Bicarbonate.

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$$

Water gathered in a limestone district therefore contains calcium bicarbonate and this has a pronounced effect on the water, making it "hard." That is, the water, besides feeling hard to the touch, does not immediately form a lather with soap. Some of the carbon dioxide is driven off when this water is boiled and insoluble calcium carbonate is formed (see page 176) which is deposited on the sides of the vessel, e.g. the kettle or boiler, as a white "fur." Such hard water is not entirely suitable for domestic use or for such industries as laundries and is usually "softened." As has been seen it can be softened by boiling since then carbon dioxide is expelled and the calcium carbonate is precipitated. Thus:

Calcium Bicarbonate = Calcium Carbonate ↓ + Carbon Dioxide + Water.

$$Ca(HCO_3)_2 = CaCO_3 + CO_2 + H_2O$$

But this is not a convenient method when thousands of gallons are used daily and another method of softening it is to add lime in just a sufficient quantity to neutralize the "excess" carbon dioxide Thus:

Excess Carbon Dioxide + Lime = more Calcium Carbonate.

$$CO_2 + Ca(OH)_2 = CaCO_3$$

Now wherever chalk or limestone occurs there usually occur with it other calcium salts, e.g. calcium sulphate, as well as magnesium salts. These, being soluble in water, also cause hardness for the following reason. Soap is actually a salt called sodium stearate (page 174) and forms a lather when it dissolves in water. But calcium stearate, unlike sodium stearate, is insoluble and so cannot form a lather. So that when soap which is soluble is added to water containing soluble calcium salts the insoluble calcium stearate is formed, which is useless, and the soap is wasted.

Sodium Stearate + A Soluble Calcium Salt → Calcium Stearate ↓.

Unlike calcium and magnesium bicarbonates, which can be removed as insoluble carbonates and carbon dioxide by boiling, calcium sulphate and magnesium sulphate cannot be so removed. Thus when hard water is heated in a boiler where the purpose is to turn

as much water as possible into steam the concentration of the sulphates becomes so great that in time some of them are deposited on the walls along with the calcium carbonate. This produces a hard mass which lines the inner wall of the boiler and is known as boiler scale.

Hardness due to the bicarbonates of calcium and magnesium which can be removed by boiling is termed temporary hardness.

Hardness due to the sulphates (and other salts) of calcium and magnesium which cannot be removed by boiling is termed permanent hardness.

In one process of softening permanent hard water washing soda is used and double decomposition takes place thus:

Sodium Carbonate + Calcium Sulphate = Calcium Carbonate + Sodium Sulphate.

$$Na_2CO_3 + CaSO_4 = CaCO_3 + Na_2SO_4$$

A similar reaction occurs with magnesium sulphate.

In many places a mixture is used containing just sufficient lime to soften the temporary hard water together with washing soda for the permanent hardness.

Many of the small domestic water softeners contain a substance known as permutite. It is a complex substance, but for the present purpose it may be regarded as a salt, sodium permutite. The hard water trickles slowly through the permutite and the calcium salts in it react forming calcium permutite. Thus:

Sodium Permutite + Soluble Calcium Salts = Calcium Permutite + Sodium Salts.

In time all the sodium permutite has been changed to calcium permutite but a peculiar chemical change can be brought about—one which is the reverse of the previous one. A saturated solution of common salt is put into the container and left there for some time, when sodium permutite is reformed together with calcium chloride. The permutite is washed and can be used again; it has been revivified thus:

Calcium Permutite + Sodium Chloride = Sodium Permutite + Calcium Chloride.

Uses of Lime.—Slaked lime has many uses. Its alkaline nature makes it a valuable neutralizer of the acids in the soil, and farmers use large quantities. It is also used as whitewash. Mortar is made by mixing slaked lime and sand with water. After it has

been put between two bricks in time the water evaporates and the lime sets. Gradually the lime of the mortar combines with the atmospheric carbon dioxide and is converted into hard calcium carbonate, but it takes some years before all the lime has been so converted.

When the gas chlorine is passed over solid slaked lime the substance bleaching powder or chloride of lime is formed. This is a very useful substance (page 190).

Stalagmites and Stalactites.—It has been mentioned that when rain-water percolates through limestone or chalk it becomes a dilute solution of calcium bicarbonate. Picture a drop of this coming through the roof of a cave in limestone. The drop falls to the floor of the cave and in time the water evaporates leaving insoluble calcium carbonate. In the course of centuries sufficient calcium carbonate has been deposited to form long thick pillars of chalk known as stalagmites. Similar deposits are formed hanging from the roof of the cave and are known as stalactites.

CHAPTER XVIII

FUEL, FOOD AND COMBUSTION

WHEN a piece of wood is set on fire at one end the flame gradually spreads until all the wood has burnt away. But the wood does not begin to burn until it has been raised to a certain temperature called the ignition temperature.

The burning of wood is a chemical change in which the heat produced at the end first set on fire is more than enough to set fire to the wood next to it, and so the flame spreads. But the flame would not spread unless there was a sufficient supply of oxygen to enable the chemical changes to take place. There are two essentials, therefore, before wood will burst into flames: it must be heated to, or above, its ignition temperature and there must be a sufficient supply of oxygen. These conditions apply to the burning of most substances. When a substance burns in air oxidation takes place. Wood, for example, contains the elements carbon and hydrogen, which two elements are oxidized during burning to carbon dioxide and water. The production of carbon dioxide can be shown by burning a few small pieces of wood under a funnel and by drawing the products of combustion through lime-water. This turns milky. A similar result is obtained when a candle (Fig. 164) or coal-gas is burnt under the funnel. The production of water is readily demonstrated by allowing the flame to impinge on the surface of a flask the inside of which is kept cool by running water (compare Fig. 64). The drops of liquid which collect turn anhydrous copper sulphate blue.

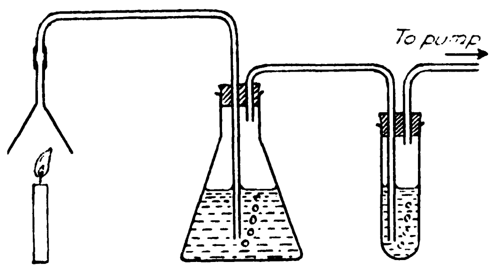


FIG. 164

All our common fuels contain the element carbon and so far it has been assumed that carbon dioxide is formed when this substance burns in air or in oxygen. This gas is not, however, always formed, for if there is an insufficient supply of oxygen another gas, carbon monoxide, is formed. This gas contains less oxygen relative to the weight of carbon, thus:

In carbon dioxide 12 grams of carbon are united with 32 grams of oxygen.

In carbon monoxide 12 grams of carbon are united with 16 grams of oxygen.

The two gases have many different properties; carbon monoxide does not affect litmus or lime-water and is very poisonous, small quantities being sufficient to cause death. The gas is readily oxidized to carbon dioxide when it burns in air or in oxygen, thus:

$$\text{Carbon Monoxide} + \text{Oxygen} = \text{Carbon dioxide.}$$

$$2CO + O_2 = 2CO_2$$

It is sometimes produced during burning as will be mentioned later.

Coal.—This is one of the commonest fuels and is found in many parts of England. Its origin is interesting. There is evidence which leads to the belief that coal has been formed by the decay of plants which lived thousands upon thousands of years ago, and occasionally fossils of long-extinct types of plants are found in coal. Layer after layer of dead plants fell to the ground and in time became covered over with earth and the remains of other plants. The bottom layers were compressed by the top and little air got to them. Hence the plants did not rot as they would in air but gradually lost the water vapour and many gases. In time the immense pressure of the earth and rocks on top compressed them into a solid mass of coal.

Coal consists mainly of carbon with some hydrogen and oxygen. Bituminous coal, the soft or common coal, contains about 88 per cent. of carbon, while anthracite, a hard coal, contains 94 per cent. of carbon. When coal is burned in an open grate oxidation takes place with the production of carbon dioxide and water, together with soot and smoke (page 209).

Coal-Gas.—Entirely different reactions take place when coal is heated so that air cannot get to it. Such a heating is called destructive distillation and this process takes place when coal-gas is manufactured. Coal-gas is a very important fuel and its manu-

facture and distribution will be dealt with later (page 216). It is really a mixture of gases, approximately half of it being hydrogen, the other important gases being compounds of carbon and hydrogen called hydrocarbons, and carbon monoxide.

When the coal-gas is burnt in a plentiful supply of air (page 181) the carbon of the hydrocarbons is oxidized to carbon dioxide and the hydrogen to water. Hydrogen burns with a non-luminous flame, i.e. it does not give out light; the light of the old-fashioned gas-burner is given by the burning of the hydrocarbons in the gas and is caused by the presence of white-hot particles of carbon which have not been oxidized. The presence of these particles of carbon can be demonstrated by putting a cold piece of porcelain in a luminous gas flame; it is soon covered with soot, i.e. small particles of carbon. Such a flame is not of much use in a laboratory for it would form deposits of soot on all the vessels which were heated.

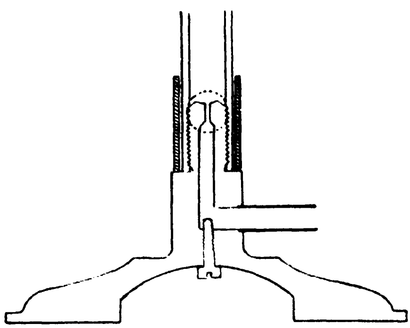


Fig. 165

A German, Robert Bunsen, invented the burner now used in the laboratory. The coal-gas is forced through the small hole, Fig. 165, and owing to the pressure in the mains, it rushes out with great force, carrying with it the air which is drawn in through the hole at the bottom. (Compare the rush of air which follows in the wake of an express train.) Thus the coal-gas is mixed with air when it gets to the top. There is sufficient oxygen present to oxidize all the carbon so that there are no unoxidized white-hot particles present. The principle of the bunsen-burner is used in gas-ovens and gas-fires (page 220).

Water-Gas.—Another gaseous fuel is water-gas, which is a mixture of carbon monoxide and hydrogen. This is made by passing steam over white-hot coke (which is a form of carbon).

Carbon + Steam = Carbon Monoxide + Hydrogen.

$$C + H_2O = CO + H_2$$

The white-hot coke is contained in a large tower and steam is blown through it for a very short time and the water-gas collected. The steam tends to put out the burning coke, so it is then shut off and

air blown through to revivify the fire. Steam is again admitted, then air, and so on. This gas readily burns in air, the carbon monoxide to form carbon dioxide, the hydrogen to form water. Thus:

$$\text{Water Gas} + \text{Oxygen} = \text{Carbon Dioxide} + \text{Water.}$$

$$CO + H_2 + O_2 = CO_2 + H_2O$$

Producer-gas is formed in a similar way, using air instead of steam. The producer-gas is composed mainly of carbon monoxide together with the nitrogen of the air which has not combined with the coke (or coal). Occasionally wood, sawdust, are used instead of coke.

Liquid Fuels.—Petroleum occurs underground in some parts of the world, and when a well is bored the oil may gush up to the surface and rise many feet into the air. This oil is a mixture of many different substances, most of them composed of hydrogen and carbon, being consequently known as hydrocarbons. The crude oil is placed in a retort and heated gently. One of the first substances to be given off is petrol, which is collected. The temperature of the retort is then increased when naphtha is obtained. At a higher temperature paraffin oil is yielded and left in the retort are paraffin wax and substances which act as lubricating oils. (The heating is done under reduced pressure so that lower temperatures bring about the above changes.)

These liquid fuels all burn in oxygen to give carbon dioxide and water; they are very similar in composition, the only difference being in the relative proportions of carbon and hydrogen. Thus:

$$\left.\begin{array}{l}\text{Hydrocarbons, e.g. Petrol,}\\ \quad\text{Paraffin, Benzene, etc.}\end{array}\right\} + \text{Oxygen} = \text{Carbon Dioxide} + \text{Water.}$$

It has been seen that the products of oxidation of all these fuels, be they solids, liquids or gases, are carbon dioxide and water, provided a sufficient amount of oxygen is present for complete combustion. If the oxygen supply is inadequate then either carbon monoxide or soot or smoke or all three are formed.

There are many chemical changes in which the evolution of heat is not at first apparent, and many of these are cases where oxidation occurs. For example, when iron rusts in moist air the change taking place is one of oxidation, since iron oxide or rust is formed. Actually, heat is evolved during this change, but the change takes place very slowly and the heat is dissipated as it is formed. Iron is prevented from rusting by paint; the paint forms

a skin over the metal and so prevents the air from getting to it. The so-called tin cans, etc., are made of sheet iron coated with a layer of tin; similarly galvanized iron, used for pails, is sheet iron coated with zinc, and many of the enamel vessels are of sheet iron covered with enamel. In each case the covering substance is used to prevent the air from getting to the iron and so causing the formation of rust. The substance linseed oil also undergoes slow oxidation in the air. When the oil is thinly spread and exposed to the air, the oxygen of the air combines with the oil producing a tough "skin." Many paints contain linseed oil, turpentine and a coloured pigment. The skin is transparent and the colour of the paint shows through it, but it does not allow oxygen to pass through it and so prevents the air and water from reaching the painted iron or wood which would otherwise rust or rot away.

Spontaneous Combustion.—In many examples of oxidation, the heat which is given off cannot escape. For example, oxidation takes place in a heap of oily rags such as cotton waste. The chemical reaction between the oxygen of the air and the carbon and hydrogen contained in the oil produces heat, but the reaction proceeds very slowly so that the heat is also evolved very slowly. Cotton, however, is a poor conductor of heat and so the heat is not conducted away. Instead, the temperature inside the heap gradually increases until the ignition point is reached and the heap sets on fire. In a somewhat similar way fires may occur in the coal bunk of a ship. Finely powdered coal undergoes slow oxidation. Although the coal, when shipped, is in lumps the constant rolling of the ship causes some of it to become finely powdered. The heat produced by the slow oxidation of the powdered coal in the middle of the heap does not escape, more heat is produced, and in time the heap sets on fire. A similar explanation of the spontaneous firing of a haystack has been given. Hay which is stacked before it is dry undergoes slow combustion, and the stack takes fire for reasons similar to the ones just given. (There is, however, another explanation for the firing of a haystack.) Slow combustion, however, is not always a nuisance as it obviously is in the cases quoted above, but use can be made of it as was indicated by the use of linseed oil in paints and putty.

Foods.—It is difficult to believe that the respiration of plants and animals is similar, from a chemical standpoint, to the burning of fuels, but such is the case. The first inkling of similarity is apparent in the production of carbon dioxide and water vapour in

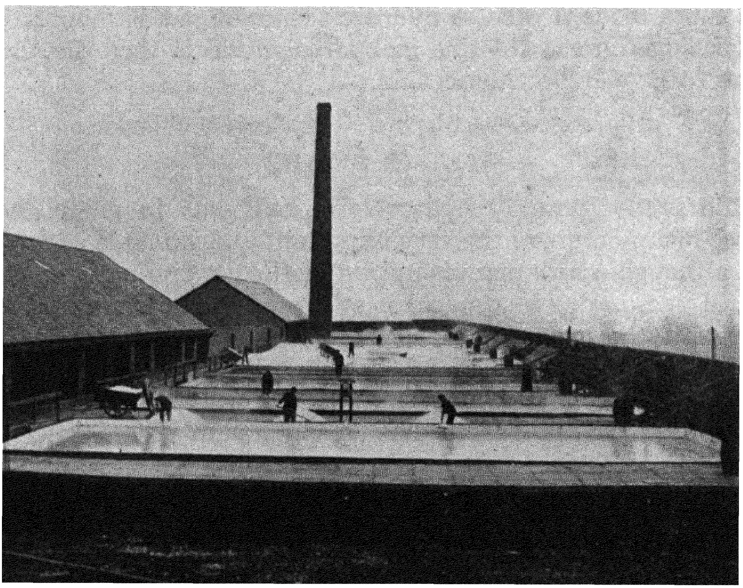
breathing, for these two substances are formed when most fuels are burned. Indeed, respiration is a process of oxidation and is also one of slow combustion. One foodstuff, sugar, can be considered in this connection as an example.

Sugar consists of the elements carbon, hydrogen and oxygen, and when it is heated in a combustion tube and a stream of oxygen passed over it carbon dioxide and water vapour are formed. These products are formed when sugar is oxidized in the body of the plant or the animal and the same quantity of heat is produced whether the same weight of sugar is oxidized quickly in the laboratory or slowly in the body.

CHAPTER XIX

COMMON SALT AND ITS DERIVATIVES

COMMON salt, or sodium chloride, is very abundant in many countries. Large deposits of it are found underground in Cheshire where it was formerly mined and brought in lumps to the surface as " rock salt." Nowadays, most of the mines are flooded



Courtesy of Salt Union Ltd.

FIG. 166

Evaporation of Brine : Open-pan Method

with water, either purposely or otherwise, and the salt solution is pumped to the surface. This is a moderately pure solution and salt is obtained from it by the process of evaporation. In the open-pan method, Fig. 166, the solution is run into large tanks which are

heated from below. The salt crystals as they are formed are raked to one side and shovelled out. The wet salt is packed into wooden moulds, and when it has set it is taken out, dried, and marketed in the familiar rectangular blocks.

In tropical and Mediterranean countries the supply of salt is obtained from the sea. Shallow pits or basins are dug in the sand and filled with sea-water. The heat of the sun causes the water to evaporate, salt being left behind.

The domestic uses of common salt, e.g. in cooking, are well known; it is also used to cure meat and to preserve fish. In addition it is used to manufacture many valuable substances, some of which will now be mentioned.

Hydrochloric Acid.—The preparation in the laboratory of hydrochloric acid from common salt has already been described (page 170) and the acid is still manufactured by a similar process. In a more modern process hydrogen chloride gas is manufactured by burning the gas chlorine in hydrogen and is then dissolved in water to give hydrochloric acid.

Hydrogen + Chlorine = Hydrogen chloride.

$$H_2 + Cl_2 = 2HCl$$

Chlorine.—Formerly hydrochloric acid was in great demand for the manufacture of the very important and valuable gas chlorine and, although a new manufacturing method is gradually displacing the old one, hydrochloric acid is still used in the laboratory preparation of the gas. Hydrochloric acid is composed of hydrogen and chlorine; a substance rich in oxygen will oxidize it, forming water with the hydrogen and liberating the chlorine. Common oxidizing agents used are manganese dioxide, potassium permanganate and potassium chlorate.

Fig. 167 shows the apparatus used with manganese dioxide which is put in the flask and moistened thoroughly with water. Concentrated hydrochloric acid is poured down the thistle funnel and the contents are gently heated. The heat drives over some of the hydrogen chloride, but this gas is very soluble in water whereas chlorine is not. The mixture of gases is passed through water, where the hydrogen chloride dissolves, and then through concentrated sulphuric acid which dries the remaining chlorine. This is then collected as shown since it is heavier than air.

Instead of using hydrochloric acid a mixture of common salt and manganese dioxide can be put in the flask, covered with water and

concentrated sulphuric acid poured on to it. The acid reacts with the salt producing hydrochloric acid which then acts with the manganese dioxide.

Manganese Dioxide + Hydrochloric Acid = Chlorine
+ Manganese Chloride + water.

$$MnO_2 + 4HCl = Cl_2 + MnCl_2 + 2H_2O$$

Most of the chlorine used for commercial purposes and in industry is now made directly by the electrolysis of a solution of common salt. Two other valuable substances, sodium hydroxide and hydrogen, are formed (page 149). The uses of hydrogen have been

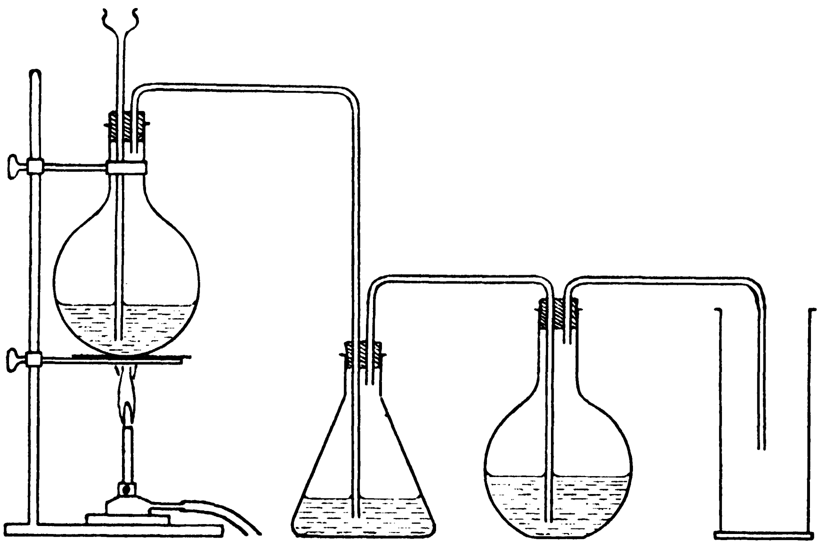


FIG. 167

given (page 65); sodium hydroxide or caustic soda is used in the manufacture of soap, paper and numerous other substances, and also as a cleansing agent.

Properties of Chlorine.—

(*a*) It is a yellowish green, heavy gas, with a suffocating smell.
(*b*) It is poisonous and a germicide.
(*c*) It reacts vigorously with many metals, e.g. Dutch metal, which contains much copper, bursts into flames when placed in a jar of it.

(*d*) It reacts vigorously with many non-metals, e.g. phosphorus.
(*e*) It is non-inflammable in air, but burns in an atmosphere of hydrogen forming hydrogen chloride.
(*f*) Chlorine can be easily liquefied and stored or transported in steel cylinders.

Uses of Chlorine.—Another method of " storing " chlorine is to manufacture bleaching powder. This is done by exposing dry slaked lime to the gas. The lime takes up the chlorine and the product is known as bleaching powder. This readily yields its chlorine on the addition of a dilute acid or even on exposure to air.

Chlorine is also absorbed by a solution of sodium hydroxide forming sodium hypochlorite which can also be regarded as stored chlorine.

In the presence of water, chlorine is a powerful bleaching agent. The chlorine, it is believed, acts on the water, producing nascent or atomic oxygen and this oxygen, being in a very active state, destroys the colouring matter by oxidizing it.

Water + Chlorine = Hydrochloric Acid + Nascent Oxygen.

$$H_2O + Cl_2 = 2HCl + O$$

This property can easily be demonstrated in the laboratory by placing a piece of wet litmus paper, red or blue, into a jar of the gas ; the paper is immediately bleached white.

Colouring Matter + Nascent Oxygen = Colourless Matter.

Pure liquid chlorine is not frequently used for bleaching for it is difficult and dangerous to handle. The coloured cloth, which must not be of wool, since chlorine destroys its nature, is dipped in a very dilute solution of sulphuric acid and then into a solution of the bleaching powder. Chlorine is liberated by the action of the acid on the bleaching powder and bleaching results as explained above. In many laundries a solution of sodium hypochlorite is used, for if bleaching powder were used there would be a danger of leaving small solid pieces of lime on the article bleached.

Chlorine, either moist or in solution, is a powerful germicide and disinfectant. As explained before, nascent oxygen is liberated by its action on water and this destroys bacteria and " germs " very quickly. In most towns the drinking-water supply is chlorinated (page 215) as is the water in many public swimming-baths.

Chlorine was the first poison gas to be used during the Great War ;

later a compound of chlorine with carbon monoxide, called phosgene, was used. Mustard gas, another dreaded war poison, also contains this element, though curiously enough, material wet with liquid mustard gas can be decontaminated by using bleaching powder. Chlorine is also used in the manufacture of chloroform and carbon tetrachloride (page 166).

Baking Soda, or Sodium Bicarbonate ($NaHCO_3$) is manufactured by bubbling carbon dioxide and ammonia through a saturated solution of common salt when the following reaction takes place:

Salt + Carbon Dioxide + Ammonia = Sodium Bicarbonate + Ammonium Chloride.

$$NaCl + CO_2 + NH_3 + H_2O = NaHCO_3 + NH_4Cl$$

Sodium bicarbonate ($NaHCO_3$) which is not very soluble is deposited and then filtered off.

Baking soda readily yields its carbon dioxide either on heating or on treatment with an acid (all carbonates yield carbon dioxide with an acid). This property makes it of value in baking powder. There are many varieties on the market, but most baking powders consist of sodium bicarbonate and a solid acid such as cream of tartar, together with other substances, e.g. starch, flour, alum. Carbonates and acids do not react in the solid, but as soon as water is added they react, producing carbon dioxide. This gas puffs up the dough, making it lighter.

Health salts also contain sodium bicarbonate with a solid acid and laxative salts. The carbonate and acid do not react when dry but when water is added carbon dioxide gas is given off, producing an effervescent drink.

Washing Soda ($Na_2CO_3.10H_2O$) is made by heating sodium bicarbonate which has been manufactured as mentioned above. The following reaction takes place—

Sodium Bicarbonate = Sodium Carbonate + Carbon Dioxide + Water.

$$2NaHCO_3 = Na_2CO_3 + CO_2 + H_2O$$

The carbonate is dissolved in water; the solution is evaporated until crystallization will occur and allowed to stand, when crystals of washing soda ($Na_2CO_3.10H_2O$) separate out (page 162). Besides being used to soften water (p. 179) and in the house, it is also used in the manufacture of glass and soap and various "cleansers."

Glauber's Salts (Sodium sulphate : $Na_2SO_4.10H_2O$) are made by the action of sulphuric acid on common salt.

Sodium Chloride + Sulphuric Acid = Sodium Sulphate
+ Hydrochloric Acid.

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2\ HCl$$

They are used for medicinal purposes as a purgative, and in the manufacture of glass.

CHAPTER XX

SULPHUR AND ITS COMPOUNDS

SULPHUR occurs free in Nature, particularly in the volcanic regions of Sicily and also in parts of North America. Its compounds with other elements are very common, e.g. galena (lead sulphide), iron pyrites (iron sulphide or fools' gold), zinc blende (zinc sulphide), etc. It has been known to mankind for centuries and is the substance commonly called brimstone. Sulphur melts when heated and this property is made use of in its extraction. The crude ore is piled in heaps in brick kilns and set on fire. Some of the sulphur burns away and the heat produced melts the rest of it which runs out of the bottom into moulds. It sets solid in the form of the familiar sticks. The Frasch process is used largely in America. Water, heated under pressure to a high temperature, is pumped into the earth containing the crude sulphur. The water melts the sulphur, which is then forced to the surface as a liquid by the use of compressed air.

Sulphur Dioxide.—When sulphur is burned in air or in oxygen the gas sulphur dioxide is formed and the same gas is also produced when most sulphides, e.g. iron pyrites, are strongly heated in a current of air. The gas is manufactured by similar processes. It is a colourless gas with a pungent smell and is suffocating. It is very soluble in water producing an acid solution (sulphurous acid), but this acid is unstable and is slowly oxidized to sulphuric acid.

The gas is more than twice as heavy as air and is easily liquefied. Liquid sulphur dioxide can be purchased in glass bottle syphons from which an ample supply can be obtained tc demonstrate the properties of the gas in the laboratory.

Bleaching.—Moist sulphur dioxide readily bleaches most coloured materials, e.g. rose petals, woollen goods, wood pulp, etc. It is said to react first with the water, producing sulphuric acid and nascent hydrogen. The hydrogen then bleaches

the colour by reducing the dye, changing it into a colourless substance.

(i) Sulphur Dioxide + Water = Nascent Hydrogen + Sulphuric Acid.

$$SO_2 + 2H_2O = 2H + H_2SO_4$$

(ii) Coloured Substance + Nascent Hydrogen = Colourless Substance.

Sulphur dioxide is used extensively to bleach woollen materials. Blankets, for example, are moistened and put in buildings containing pots of burning sulphur which forms sulphur dioxide with the oxygen of the air. It is also used to bleach straw and silk as well as the wood pulp which is used in the manufacture of paper. Wool, straw and silk cannot be bleached by chlorine for it spoils the " nature " of them. It is interesting to compare the two bleaching agents; both require water, but whilst the sulphur dioxide bleaches by reducing the coloured matter (by nascent hydrogen) chlorine bleaches by oxidizing it (by nascent oxygen). In each case the coloured matter is changed into a different and non-coloured chemical substance.

Sulphur dioxide is also used to bleach sugar. Sugar, on coming from the evaporating pans is brownish coloured; most people prefer it white and sulphur dioxide is used to whiten it.

Sulphur dioxide is a powerful germicide (again compare chlorine), hence its use in fumigation when, besides killing the germs, it will also destroy many small insect pests. Its chief use, however, is in the manufacture of sulphuric acid.

Sulphuric Acid.—One method of manufacturing this acid has already been described (page 168). Another method is to pass sulphur dioxide and oxygen (air) into large lead chambers. Oxides of nitrogen and water are also passed into the chambers and sulphuric acid is formed. This process is called the " lead chamber " process.

The common name of the acid is " oil of vitriol," the name being derived from a former method of preparing the acid. The acid forms salts known as sulphates (page 172). Some of these are white and almost transparent, others are blue or green, but also almost transparent. Hence the earlier chemists called the sulphates, vitriols (from vitreus = glass), and since sulphuric acid, which is oily, was obtained by distilling a vitriol the acid goes by the name of " oil of vitriol."

Sulphuric acid is widely used to manufacture and prepare other substances, many examples of which have been given, e.g. nitric acid, hydrochloric acid, Glauber's Salts, ammonium sulphate (a valuable fertilizer). It is also used in the manufacture of many explosives (page 197) and dyes. Dilute acid is used in accumulators (page 155).

Hydrogen Sulphide.—Sulphur forms numerous sulphides, i.e. compounds of sulphur and one other element. Some of them when treated with dilute hydrochloric acid yield hydrogen sulphide. This gas is usually prepared in the laboratory in Kipp's apparatus which is an apparatus devised to give a supply of the gas as and when it is required. In Kipp's apparatus, Fig. 168, ferrous sulphide sticks are placed in the central bowl. Dilute hydrochloric acid is poured down the funnel-shaped top until it fills the bottom bowl, rises through the narrow annular space and just covers the sulphide. The sulphide and acid react, producing the gas. When it cannot escape the pressure in the central bowl becomes greater than atmospheric and the acid is forced out of this compartment, some of it rising into the funnel. As soon as the tap is opened the gas comes out, for the pressure is then restored to that of the atmosphere and the acid falls from the top bowl into the bottom and rises through the annular space to cover the sulphide. Gas is therefore generated when the tap is open, but on its closure the excess pressure generated causes the acid to return as described above.

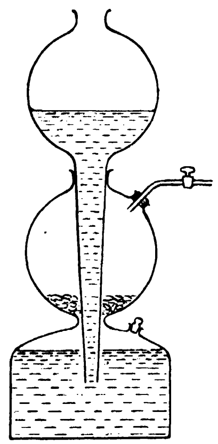


FIG. 168

The gas is colourless with a smell of rotten eggs.

It is slightly soluble in water and reacts with most metallic salts to give sulphides. It is found in many natural waters (e.g. those at Harrogate contain it), and is one of the products of the distillation of coal.

CHAPTER XXI

NITROGEN AND ITS COMPOUNDS

THERE is an abundant supply of nitrogen in the atmosphere, yet until this century little commercial use was made of it and most of the nitrogen compounds were prepared from ammonia, from Chile saltpetre (sodium nitrate) or from nitre (potassium nitrate). Chile saltpetre is found in large quantities on the coast of Chile and readily reacts with sulphuric acid to give nitric acid (page 169).

Sodium Nitrate + Sulphuric Acid = Nitric Acid.

$$2NaNO_3 + H_2SO_4 = Na_2SO_4 + 2HNO_3$$

In 1898, however, it was pointed out that the Chile deposits could not last for ever and new sources were sought. The air contains millions of tons of nitrogen and attempts were made to convert atmospheric nitrogen into nitric acid. It was known that this was done, on a very small scale indeed, in thunderstorms (and this possibly accounts for some of the nitrates in the soil), so attempts were made to imitate lightning. The attempts were successful and in places where electricity is cheap the following method is used: An electric discharge is passed between two electrodes and it is drawn out by powerful electro-magnets. In effect, a sheet of flame many feet in diameter is produced by the electric discharge and the air is passed through it. A little nitrogen combines with some of the oxygen of the air (just as it does during lightning) to produce oxides of nitrogen and these, when dissolved in water, yield nitric acid. Other methods are now also used, one of which is described later (page 198).

Uses of Nitric Acids and its Compounds.—Explosives. It is said that Roger Bacon (*c.* 1250) first used gunpowder in Europe. Nowadays it is made by mixing 75 parts of nitre with 15 parts of charcoal and 10 parts of sulphur. Nitre is very rich in oxygen and when gunpowder is set alight this oxygen immediately combines

with carbon to produce carbon dioxide and monoxide, and with sulphur to form sulphur dioxide. In addition, nitrogen gas is set free from the nitre and potassium carbonate and sulphate are left. A small mass of the solid gunpowder immediately yields an enormous volume of these gases, and if the gunpowder is fired in an enclosed space the gases, in endeavouring to escape, cause an explosion.

Picric Acid, another explosive, is often obtained by treating an acid called carbolic acid with sulphuric acid and then the resulting product with nitric acid. It is a more powerful explosive than gunpowder and can be melted and poured into blocks to form, when set, the substance lyddite.

When glycerine is dropped into a mixture of sulphuric and nitric acid another explosive, nitro-glycerine, is produced. This compound, when mixed into a paste with an earthly material called "kieselguhr" (mainly silica), produces dynamite. Gun-cotton is made by soaking cotton-wool in a mixture of sulphuric and nitric acids. In the manufacture of the chief modern explosive, T.N.T. (trinitrotoluene), nitric acid is also required. Even the detonators contain nitrogen, e.g. mercury fulminate. It will be seen from this that nitric acid is of great importance during war, but explosives are also used in industries in time of peace, e.g. for mining and in quarries when blasting.

Nitric acid, however, has many other uses besides the production of explosives. It is used very extensively in the manufacture of ammonia (see later), of dyes and medicines, but the chemistry of these substances is too difficult to be dealt with here. It acts on the cellulose from plant tissues to form celluloid, which is used for making films. The acid is the basis of many artificial fertilizers, particularly those of the nitrate family.

Ammonia. In pre-War days most of the ammonia was obtained from the gas works by the process described on page 218. The modern process is one of the chemical romances of the Great War, for ammonia is readily converted into nitric acid, which, as has been mentioned, is necessary for the manufacture of most explosives.

Early in the War the Germans realized possible difficulties in getting Chile saltpetre from which to make their nitric acid, owing to the blockade. Fortunately for them a method of making ammonia from the nitrogen of the air was known but up to then it was chiefly a laboratory process. One of their eminent chemists, **Haber**, put the process on an industrial scale. Nitrogen, from the

air, and hydrogen prepared by one of the methods given on page 64, were compressed to 200 atmospheres in the presence of a catalyst and some of the gases combined to give ammonia.

$$\text{Nitrogen} + \text{Hydrogen} = \text{Ammonia.}$$

$$N_2 + 3H_2 = 2NH_3$$

The ammonia was then converted into nitric acid by passing it, mixed with oxygen, over a heated catalyst (platinum).

$$\text{Ammonia} + \text{Oxygen} \xrightarrow[\text{catalyst}]{} \text{Nitric Acid} + \text{water.}$$

$$NH_3 + 2O_2 \longrightarrow HNO_3 + H_2O$$

This process is now widely used in many countries, both for the manufacture of ammonia and for that of nitric acid.

Properties of Ammonia.—(1) It has a very pungent smell, and is very soluble in water.

(2) Although it is usually said that ammonia dissolves in water, actually the two combine forming a compound called ammonium hydroxide.

(3) Ammonium hydroxide is an alkali; it reacts with acids forming ammonium salts. Thus:

(*a*) with hydrochloric acid it forms ammonium chloride, or sal ammoniac.

Ammonium Hydroxide + Hydrochloric Acid = Ammonium Chloride + Water.

$$NH_4OH + HCl = NH_4Cl + H_2O$$

(*b*) with sulphuric acid it also forms a salt, ammonium sulphate.

Ammonium Hydroxide + Sulphuric Acid = Ammonium Sulphate + Water.

$$2NH_4OH + H_2SO_4 = (NH_4)_2SO_4 + 2H_2O$$

(*c*) and with nitric acid.

Ammonium Hydroxide + Nitric Acid = Ammonium Nitrate + Water.

$$NH_4OH + HNO_3 = NH_4NO_3 + 2H_2O$$

Ammonium Nitrate, when heated, yields nitrous oxide (N_2O) or laughing gas, which is used by the dentist. This gas is an anæsthetic and may cause the patient to go into hysterical laughter, hence its name.

Ammonia and its Compounds.—Ammonia gas is oxidized to nitric acid by passing a mixture of the gas and oxygen (air is used) over heated platinum (page 198). A solution of the gas in water is used as a cleaning agent since it readily dissolves grease.

Sal ammoniac (ammonium chloride) is used in some of the electrolytic cells (page 153), ammonium sulphate is a very valuable fertilizer and ammonium nitrate can be used for the manufacture of laughing gas.

When ammonia gas is pumped into steel coils, which are water-cooled, the pressure inside the coils gradually rises and in time the gas turns into a liquid, which is stored in steel cylinders. This is liquid ammonia and not a solution and must be clearly differentiated from liquor ammoniae fortis—a concentrated solution of the gas in water.

Liquid ammonia at room temperature and pressure readily turns into the gas and this evaporation produces a cooling effect (page 86). Use is made of this in modern refrigerators.

All living organisms contain nitrogen combined with other elements; it is contained, for example, in the hair, hoofs, horns of animals and in most vegetable matter. Coal is formed by the decomposition of plants (see page 182) and contains about 1 per cent. of nitrogen. When these substances are burned in air in the usual manner, the nitrogen compounds are decomposed and oxidized, but when they are heated in a vessel in which there is no air then ammonia is given off. It has been known for centuries that ammonia is produced when hair, hoofs, horns, etc., are heated, hence its old name of spirits of hartshorn. Large quantities are produced annually during the manufacture of coal-gas (see page 218). Indeed, until recently this was the source of the ammonia of commerce, but since about 1915 increasing amounts have been made by combining directly nitrogen and hydrogen (see Haber Process, page 197).

In the laboratory it may be prepared by heating an ammonium salt, usually ammonium chloride (sal ammoniac), with dry slaked lime. The mixture of these two substances is placed in a hard glass tube which is sloping slightly downwards (Fig. 169). It is heated; ammonia gas and water vapour are given off. Since the tube is sloping downwards any water formed by the condensation of the vapour does not trickle back to the hot part of the tube and cause a breakage as it might do were the tube level. The ammonia, being lighter than air, is passed into the bottom of a tower containing quicklime, which absorbs the water vapour, and the ammonia gas

is collected as shown. (N.B. ammonia combines with concentrated sulphuric acid and with calcium chloride ; hence these substances cannot be used to dry the gas.)

Ammonia can more readily be obtained in the laboratory by very

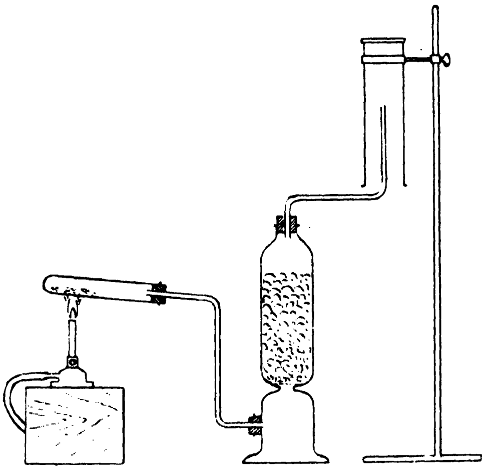


FIG. 169

gently heating liquor ammoniae fortis in a flask connected to the drying tower, etc., as before. The liquor must not be heated too strongly or an explosion might be caused owing to the rapid evolution of a large volume of the gas.

CHAPTER XXII

METALS

METALS possess certain properties not possessed by other elements, some of these being physical and others chemical properties. These differences are summarized in Table III.

TABLE III

METALS AND NON-METALS

Metals.	Non-Metals.	Remarks.
Usually solids at ordinary temperatures	Some are solid, some liquids, some gases	Mercury (a metal) is a liquid at ordinary temperatures
Malleable, i.e. can be hammered flat	Not malleable—many solids are brittle	Antimony (a metal) is brittle
Ductile, i.e. can be drawn into wire	Non-ductile	
Good conductors of heat and electricity	Bad conductors of heat and electricity	Carbon (a non-metal) conducts electricity
Freshly cut surfaces reflect light and are lustrous	Freshly cut surfaces do not reflect light	

Chemical Properties.—

Metals.	Non-Metals.	Remarks.
Form Basic Oxides With dilute H_2SO_4 yield hydrogen	Form Acidic Oxides Do not yield hydrogen with dilute H_2SO_4	page 172

Metals form two important classes of compounds, salts and oxides. The methods of preparing some of the common salts have been mentioned in Chapter XVI and their properties and uses have been given in various parts of the book. Most of the oxides are bases

and many of them occur naturally (see later). They can be prepared in the laboratory as follows:

(*a*) By heating the powdered metal, e.g. magnesium and copper, in air or in oxygen.
(*b*) By heating the solid carbonate of the metal, e.g.

Copper Carbonate = Copper Oxide + Carbon Dioxide.

$$CuCO_3 = CuO + CO_2$$

Lead Carbonate = Lead Oxide + Carbon Dioxide.

$$PbCO_3 = PbO + CO_2$$

(*c*) By heating the solid nitrate of the metal.

Copper Nitrate = Copper Oxide + Oxide of Nitrogen + Oxygen.

$$2Cu(NO_3)_2 = 2CuO + 4NO_2 + O_2$$

(*d*) By adding a solution of caustic soda to a solution of a soluble salt and heating the hydroxide which is formed.

Iron Sulphate + Sodium Hydroxide = Iron Hydroxide + Sodium Sulphate.

Iron Hydroxide = Iron Oxide + water.

Many metals form more than one oxide. Thus lead forms lead monoxide (PbO), lead dioxide (PbO_2) and red lead (Pb_3O_4). These three oxides have different properties. Thus lead monoxide reacts with hydrochloric acid to form lead chloride and water only, but lead dioxide with this acid forms lead chloride, water and chlorine:

Lead Monoxide + Hydrochloric Acid = Lead Chloride + water.

Lead Dioxide + Hydrochloric Acid = Lead Chloride + water + chlorine.

Red lead also forms chlorine with hydrochloric acid but differs in colour from the dioxide which is a chocolate colour.

Red lead is the basis of many paints for use on metals, e.g. iron. It differs in chemical composition from white lead which is also used as a basis of ordinary paints because it has good "covering" properties. White lead is lead carbonate.

Most oxides can be converted into the metal by reduction. The metallic oxide is placed in a combustion tube and heated. A

reducing gas, such as hydrogen, carbon monoxide, or coal-gas is passed over the red-hot oxide and converts it into the metal, e.g.

$$\left.\begin{array}{l}\text{Copper Oxide}\\\text{Iron Oxide}\\\text{Lead Oxide}\end{array}\right\} + \text{Hydrogen} = \left\{\begin{array}{l}\text{Copper}\\\text{Iron}\\\text{Lead}\end{array}\right\} + \text{water.}$$

$$\left.\begin{array}{l}\text{Copper Oxide}\\\text{Iron Oxide}\\\text{Lead Oxide}\end{array}\right\} + \text{Carbon Monoxide} = \left\{\begin{array}{l}\text{Copper}\\\text{Iron}\\\text{Lead}\end{array}\right\} + \text{Carbon Dioxide.}$$

Another reducing agent which can be used for this purpose is the element carbon (see below).

The Occurrence of Metals.—Only a few metals occur free in nature, that is are "native," of which gold, copper, silver, and mercury are the commonest. Most of the others are combined with another element or elements forming "ores." An ore is a mineral substance containing a metal (or metals) from which the metal can be extracted; a mineral is a substance having a definite and constant composition, and is usually found in the earth. Some of the ores of the commoner metals are mentioned below; they are mostly oxides or sulphides.

Oxides.—Hæmatite or iron oxide (Fe_2O_3), bauxite or aluminium oxide ($Al_2O_3.2H_2O$), "red copper ore" or cuprite (Cu_2O), and tinstone or tin oxide (SnO_2).

Sulphides.—Galena or lead sulphide (PbS), zinc blende (ZnS), copper glance (Cu_2S).

A few ores are carbonates, e.g. malachite or copper carbonate ($CuCO_3$, $Cu(OH)_2$), others are chlorides, e.g. carnallite ($MgCl_2.KCl.6H_2O$), while others again are relatively still more complex substances.

The Winning of Metals.—Many metals are won from their ores by the process of reduction with charcoal or carbon. The method can be illustrated in the laboratory using a compound of lead or silver. The metallic compound is intimately mixed with fusion mixture and a drop or two of water. The mixture is then placed in a hole made in a block of charcoal and heated before the mouth blowpipe. The heat melts the mixture and the carbon of the block reduces the compound to the metal which runs in the molten fusion mixture and forms a metallic bead. The molten fusion mixture prevents the red-hot metal from becoming oxidized as it cools, since it keeps off the air. Occasionally a bead of copper can be obtained from a copper salt by this method but this laboratory

experiment is not a satisfactory one for winning most of the metals from their compounds. In industry, many oxide-ores are reduced by the use of charcoal, coke or coal. Certain sulphide-ores are first roasted in air to yield oxides which are then reduced as are the oxides formed when certain carbonate-ores are strongly heated. Sometimes the carbon of the coke, etc., does the reduction, in other processes the carbon is first converted into carbon monoxide, which gas then reduces the metal oxide. Thus :

Metallic Oxide + Carbon = Metal + Oxide of Carbon.

or

Metallic Oxide + Carbon Monoxide = Metal + Carbon Dioxide.

The Winning of Metals.—Iron.—The common ores are oxides and they are heated with a flux in a blast furnace with coke. A blast of air is blown into the furnace and some of the oxygen of the air combines with the coke to form carbon monoxide. This reduces the iron oxide to iron, thus :

Iron Oxide + Carbon Monoxide = Iron + Carbon Dioxide.

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2$$

Copper.—Copper carbonate (malachite) is heated in air to give copper oxide. This is mixed with powdered coke and a flux and heated. The oxide is reduced to copper. When the ore, cuprite (copper oxide), is used this is also mixed with coke and a flux and then heated.

Tin.—Tinstone, an oxide, contains compounds of arsenic and sulphur as impurities. The ore is first heated and the sulphides and arsenic compounds are turned into volatile oxides and escape. The tin oxide which remains is mixed with anthracite coal, a form of impure carbon, and heated until it is reduced to tin.

The metals which can be won in this way are metals which have been known for centuries. There are many metallic oxides which cannot be so easily reduced and an electrolytic method is sometimes used. The essential process consists of passing an electric current through the molten ore of the metal, when the metal is deposited at the negative pole of the apparatus. There are many difficulties to contend with, e.g. some of the ores do not readily melt on heating and have to be mixed with other substances. A full account of this method is not possible at this stage but the commercial importance of it can be seen by the enormous increase in production of the metal aluminium. Some seventy-five years ago this metal was almost

a museum specimen, so rare was it. Nowadays about a quarter of a million tons are produced annually by the electrolytic method.

Alloys.—When a mixture containing certain metals in certain proportions by weight is heated, the metals melt and form a solution, any part of which is like any other since the metals are then uniformly mixed. This solution solidifies on cooling and the metals remain intimately and uniformly mixed in the solid. Such a solid is called an alloy. On the other hand, when a molten solution of certain metals is cooled the metals separate into definite layers and are not intimately and uniformly mixed in the solid state. Such a solid is not called an alloy.

Copper, for example, forms an alloy called bronze with tin when from 75 to 90 parts of copper are melted with from 25 to 10 parts of tin and the resulting molten mixture cooled.

Alloys can be formed by using carbon in place of one of the metals, steel being such an alloy. But to produce such carbon-iron alloys the proportions of carbon and iron have to be carefully chosen. If the proportion is 3 to 4 per cent. of carbon and the rest iron, a solid called cast iron is formed on cooling. Cast iron is not an alloy since the iron and carbon are not uniformly mixed. Because of this it is very brittle. Cast iron has a curious property of expanding a little on solidifying and is therefore used for making castings in the foundry, since owing to the expansion, clearly defined edges are obtained. The carbon in it, however, causes it to be very brittle. Wrought iron contains very little carbon, indeed it is almost pure iron ; it is soft and malleable and can be welded. This is the iron used by the blacksmith.

Steel contains a smaller proportion of carbon than cast iron does. It can be cast and welded and is also malleable. When heated to redness and cooled suddenly by being plunged into cold water it is said to be " tempered." This makes it hard so that a cutting edge can be put on it. Tempered steel is used for making many cutting instruments and tools.

Steel alloys are made of steel and much smaller proportions of other metals. Stainless steel is steel with from 9 per cent. to 16 per cent. of chromium. Unlike steel it does not rust ; it is not attacked by most acids and does not scale readily. Some of the " stainless steels " contain, in addition, a little nickel. The addition of small proportions of metals such as chromium, nickel, manganese, and the rarer metals, such as tungsten and molybdenum, makes the steel harder and tougher. Such alloys (e.g. chromium-steel) are used

for making armour-piercing shells, high-speed cutting tools, and motor-car parts which have to withstand very hard wear. Cobalt steel and tungsten steel retain magnetism much better than ordinary steel does and are used for making permanent magnets.

Copper is a soft metal but forms many alloys with other metals. It produces a hard alloy such as bronze with tin, or brass with zinc, or German silver with zinc and nickel, or coinage metal, from which pennies, etc., are made, with tin.

Other alloys containing tin are solder and type metal. Common solder is an alloy of tin and lead, and a characteristic property of the addition of one metal to another is exhibited by this alloy, for it melts at a much lower temperature than either of the pure metals Type metal is an alloy of antimony, tin and lead. The metal, antimony, has a peculiar property in that when the hot solid metal cools it expands. These three metals are mixed in a certain proportion to form an alloy. When a newspaper is being produced, each letter has to be made in metal. This metal letter is cast in a mould by a machine. On cooling, owing to its antimony content, the alloy expands slightly and so completely fills the mould so that the letter is sharply defined.

In recent years enormous progress has been made in the production of aluminium alloys. One of the most valuable characteristics of aluminium is its lightness, but because it has not a great mechanical strength pure aluminium has few uses. Both its strength and rigidity are increased by the addition to it of other metals. Aluminium alloys containing only small proportions of other metals have numerous commercial applications. The most important aluminium alloys contain copper, together with much smaller proportions of one or more of the elements magnesium, manganese, zinc and silicon. Duralumin, a common alloy, for example, contains 95 per cent. aluminium, 4 per cent. of copper and approximately $\frac{1}{2}$ per cent. each of magnesium and manganese. But other alloys of aluminium containing different proportions of other metals are gradually displacing duralumin.

Aluminium alloys have low densities (i.e. are light) ; they are very malleable and ductile and conduct heat and electricity. Many of them can be cast or wrought. No wonder that aluminium is gradually displacing other metals ! But it must be emphasized again that pure aluminium is rarely used to make things and even saucepans, etc., are made of an alloy.

Another type of alloy, the fusible alloys, can be illustrated by

Wood's metal. This is made of the metals bismuth, lead, tin and cadmium, and melts at a low temperature—(about 60° C.). Such alloys are used in sprinklers; the holes of the water-spray are plugged with this metal and when a fire breaks out the metal melts. Owing to the head of pressure in the mains the water is forced out and extinguishes the fire.

CHAPTER XXIII

SCIENCE AND THE HOME

THE HOT-WATER SUPPLY OF A HOUSE

MOST modern houses are provided with hot-water systems, the principle of which depends on the fact that water circulates by convection. This can be shown by the apparatus in Fig. 170. The water in the top vessel is coloured with a red dye stuff. The water in the flask is heated and convection currents are set up

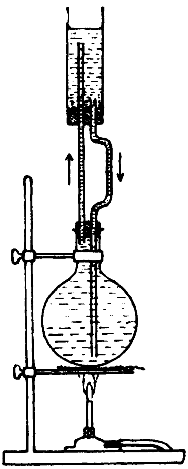


FIG. 170

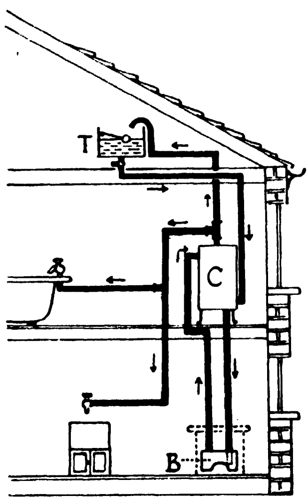


FIG. 171

(page 89). The cold water (coloured red) can be seen descending the tube to the bottom of the flask, the hot water rises up the straight tube and the water is circulating as shown by the arrows.

In small houses the hot-water boiler is built into the kitchen fireplace, which is usually provided with a special flue controlled by a damper so that when it is desired the hot products of combustion

of the fire can circulate round the boiler. The hot water is stored in the hot-water cylinder C, which must be placed above the level of the boiler. This cylinder is equivalent to the top vessel in Fig. 170 and the boiler to the flask. Fig. 171 is nearly self explanatory. The hot water rises up a tube from the top of the boiler B into the hot-water cylinder and the colder water flows through a pipe at the bottom of this cylinder back to the bottom of the boiler. When hot water is drawn off at a tap, cold water enters the hot-water cylinder from a small storage tank T placed usually between the roof and the ceiling of the top room. This tank is fitted with a ball-valve which ensures that it is always full of water, and there is an overflow pipe. There is also an expansion pipe from the hot water cylinder to the storage tank.

Heating and Ventilation.—Man is a warm-blooded animal, the temperature of the blood being kept constant at 98·4° F. by various means (page 310). Experience shows that a suitable room-temperature is about 60° F.

Of the three methods of transmitting heat only two are of importance in heating rooms. The air of the room may be warmed by convection, and so the body becomes "bathed" in warm air, or the body may be warmed directly by radiated heat. The commonest method of heating a room in England is by an open coal fire. The coal burns in a plentiful supply of air which passes through the fire and up the chimney by convection. Soft, bituminous coal (page 182) is used and this is raised to its burning temperature by a preliminary heating with paper and sticks. The coal, although largely composed of carbon, gives off inflammable gases, the escape of which can sometimes be heard when a lump of coal is burning and the burning of which is sometimes made strikingly obvious by small spurts of flame. These gases are hydrocarbons which burn to form carbon dioxide and water while the carbon of the coal is oxidized to carbon dioxide, often with the intermediate formation of carbon monoxide. (Carbon monoxide is produced when the fire has "died down" and consists of red-hot cinders, and it is often possible to see it burning at the top of the cinders with a bluish flame.) Not all the carbon of the coal is oxidized, however, and much of it escapes as small particles in the smoke together with the unburnt gases and tarry products, etc. The quantity escaping in the neighbourhood of our large industrial towns is enormous. Although only part of it falls near where it is produced it has been estimated that three or four hundred tons of

soot fall annually on each square mile in certain towns. There are various injurious effects due to the air containing such an amount of soot, tarry products, etc. The particles of soot favour the formation of fogs (page 95) and the effect of a smoke-ladened atmosphere on buildings is clearly noticeable. Some idea of this can be got from the photograph, Fig. 172. The white building had just

Courtesy of National Smoke Abatement Society

FIG. 172

Effect of Smoke on Buildings

been erected when the photograph was taken and the one on its right was then only eight years old!

The matter escaping from coal fires contains valuable substances and some of these are obtained during the manufacture of "coalite." This substance is made by heating coal in a retort to a much lower temperature than it is heated in the manufacture of coal-gas (page 217) and not all the volatile substances are expelled. Motor spirit is obtained from the distillate and the solid left, which may be regarded as intermediate in properties between coal and coke, is

"coalite." This may be burned in an open grate and has a smokeless flame since most of the substances causing smoke, etc., were expelled in the retort-process.

Modern fireplaces are built with only a little air space beneath them; indeed some fires rest on a solid base and combustion is fairly slow. The sides and backs are made of firebrick and are built so that they lean over the fire at the top. Firebrick quickly becomes very hot and will withstand high temperatures and since it is a bad conductor the heat is not conducted to the back of the fireplace but is radiated into the room. Some of the heat escapes up the chimney and from a heat-standpoint is wasted. But the convection currents which are set up assist in the ventilation of the room.

Slow Combustion Stoves (Fig. 173).—Closed stoves are more common in other European countries than in ours, although the closed anthracite stove is increasing in popularity. Anthracite is a harder form of coal than ordinary household coal; it contains more carbon, is more difficult to set on fire and burns much more slowly than a soft coal. Owing to this slower speed of burning, a considerable amount of coal must be burning at once to give out an appreciable quantity of heat. The stoves need to be filled with coal only once every twelve hours or so and the fire is usually kept continuously alight. The products of combustion are much the same as those of ordinary coal and pass out of the building by a pipe leading into the chimney.

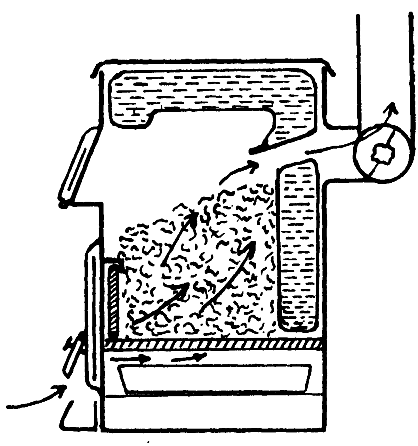


FIG. 173

While an open fire warms a room largely by radiation a closed stove does so mainly by heating the air around it. Convection currents are set up and in time all the air in the room becomes warmer. The warmer the air the drier it becomes and open vessels of water are sometimes placed near the fire to increase the humidity of the air.

Other Methods of Heating Rooms.—(*a*) Central Heating.

In England most of the central heating is done by a hot-water system. This, in principle, is similar to the one described (see Fig. 171), but a special boiler is provided and radiators are fitted (instead of wash basins, etc.). When no hot water is to be drawn off for domestic use there is no need to have a hot-water cylinder.

(*b*) Gas Fires. Page 220.

(*c*) Electric Fires. Page 226.

Ventilation.—Fresh air has an approximately constant composition and the human body is more or less accustomed to it. Although many impurities are expelled into it, its composition does not vary greatly for there are two natural purifying agents; the rain and the wind. The rain washes the air and dissolves many of its impurities and the winds scatter them. Gases readily diffuse; any gases emitted to the air soon become thoroughly mixed with the excessive volume of the air and so dispersed.

When a number of people are present in an unventilated room, the composition of the air soon changes. Expired air differs from inspired air because we take in some of the oxygen and expel carbon dioxide (page 309). Its approximate composition is 16 per cent oxygen, 4 per cent. carbon dioxide and 78 per cent. nitrogen, together with water vapour. The proportion of carbon dioxide is about 100 times larger than that in fresh air and when the same air is breathed over and over again the proportion of carbon dioxide increases rapidly.

Formerly the ill effects of being in a stuffy room were thought to be due to breathing excess carbon dioxide. Experiments show, however, that man can tolerate a bigger proportion of carbon dioxide than was previously thought to be the case, although there are limits to the quantity which can be tolerated. Some of the ill-effects are due to other causes. We breathe out much water vapour and also give off much to the air when we perspire. Consequently the air of a badly ventilated room tends to become saturated with water vapour. At a certain temperature the air can hold only a definite quantity of vapour (page 86) and when this is reached the water exuded from our pores during perspiration does not evaporate. Normally our skin is cooled by the evaporation of the sweat (page 311), and when evaporation cannot take place not only does the sweat remain but we miss the cooling effect. Hence the skin gets clammy and hot and we become generally uncomfortable. In a room in which the air is moving the air-current sweeps away the water vapour from the region just above the skin and makes

room for more to form. In the absence of air currents the air just above the skin soon gets saturated and the rate of evaporation of the sweat diminishes.

The movement of the air normally depends on convection currents which are produced since the air in the room is warmer than that outside. The warm air escapes by the ventilator near the top or through the windows open at the top, and fresh air enters through some lower opening such as through gratings, or the window open at the bottom, or under doors. The air in the room is warmed by the persons in it, but any source of heat such as a fire or a radiator raises the temperature of the air and so aids ventilation by increasing the convection currents.

The cold air is best admitted at a reasonable height from the floor so that on falling through the warmer air (which is less dense) it becomes warmer. Cold air admitted at floor-level tends to stop there and gives rise to cold feet.

An ordinary coal fire in the open grate ensures good ventilation. The hot burning gases rise up the chimney and a considerable amount of the air of the room moves towards the fire, then up the chimney quite apart from that used up by the fire. Hence the coal fire sets up air-movements and causes air to enter the room through windows and ventilators. So also does a gas fire which is provided with a flue (page 221).

THE WATER SUPPLY OF A TOWN

It is estimated that the average daily supply of water for each individual in a town is 25 gallons a day. Add to this the large volumes needed for industry and it is easy to see that a big town requires millions of gallons of water in a year. All this water has to be collected, purified and delivered. In England the water is usually obtained by one of the following methods:

(*a*) By collecting the rain which falls on the surface of moors and other large and unpopulated expanses, gathering it into cuts, rivulets and streams and leading the water into large artificially made reservoirs or into natural lakes.
(*b*) From large rivers, e.g. Oxford gets its supply from the Thames; the town of Lyons is supplied by the Rhone.
(*c*) From artificially sunk wells.

Owing to its great solvent power water is easily polluted by

animal, vegetable and mineral matter. Hence the best "surface water" is obtained by draining a limited "catchment" area from which the source of animal pollution can be largely excluded. Moors and large stretches of land situated away from towns and valleys are ideal for this purpose. Moreover, they are usually at an altitude high enough to ensure the proper pressure for the distribution of water to a town miles away (page 37). In many places artificial reservoirs have had to be constructed to collect the water and a common method is to make use of the natural surroundings by putting a dam across a deep valley. In other places use has been made of existing lakes (Thirlmere in the Lake District supplies Manchester).

Much of the rain which falls does not drain off the surface but sinks through the various layers of strata until it comes to an impervious layer and is "stored" there. In many places wells are sunk to tap these "stores" and the water pumped to the surface. For example, Deptford, Lincoln and Rome are each supplied by water obtained from wells.

No matter whether the water is collected in reservoirs or obtained from rivers or wells it is not, generally, in a fit state for drinking. It might contain three classes of impurities, floating, suspended and dissolved. There is not, as a rule, much floating matter in well-water but there is in river water and in water from the reservoirs. The water is strained through fine wire gauze screens and some of the floating matter is held back. Most of the suspended matter is, however, too small to be strained off, so the water is usually allowed to stand for a long time and the suspended matter sinks. In some cases the substance called alum is added, which causes a jelly-like substance to form around the small particles of suspended matter. The particles become heavier and sink to the bottom. Surface water contains many dissolved gases, such as hydrogen sulphide and carbon dioxide, and these are expelled mainly by aeration. The water is made to flow along open channels or else over waterfalls, and when a large surface of water is thus exposed to the air some of the gases which were dissolved in the water are given off.

All water intended for drinking is now filtered, filtration taking place on a large scale. In some places the water percolates through beds of sand, the suspended matter remaining on the sand (which has to be cleaned at intervals). In other places the water is filtered through sand by a mechanical process.

Water which is polluted with sewage may contain bacteria which cause deadly diseases. The excreta of persons suffering from these diseases may contain the bacteria responsible. It has been shown that disease-causing bacteria can even be excreted by people who are not suffering from the disease, such people being known as carriers. The bacteria may find their way into water (milk, food, etc.) either by direct contact of the water with sewage or through the agency of flies and thus cause infection and ultimately epidemics. In England and most European countries the chief water-borne epidemics are of typhoid fever, dysentery and diarrhœa. In tropical countries the deadly cholera is also water borne.

Some of the bacteria are removed during sedimentation, filtration and aeration, but not all, and if their presence is suspected the water supply is treated chemically. The common method is that of passing chlorine gas into the water. Some of the bacteria are killed directly by the chlorine gas itself, others are killed by the nascent oxygen which is produced when the chlorine acts on the water (see page 190), thus:

$$Cl_2 + H_2O = 2HCl + O \text{ (nascent)}.$$

It is of the utmost importance that the water engineer of the town has some test to ascertain whether the supply is free from these harmful bacteria. But it is not an easy matter to test water for, say, the specific bacteria causing typhoid fever. Along with these kinds of bacteria, however, another and a harmless type of bacteria is excreted, known as "bacillus coli" (plural bacilli coli). The presence of this can be ascertained by using a microscope and if it is found that many samples of the water tested (50 or 100 c.c. are used) are free from bacilli coli it is assumed that the water supply has not been contaminated or else that the bacteria causing the contamination have been killed—bacilli coli being a more vigorous type than other bacilli.

In many districts the water is hard and has to be softened. (Methods of doing this have been mentioned in Chapter XVII.) Reservoirs are situated at a higher altitude than the town they supply and, when water is obtained from rivers or wells, it is usually pumped into a storage reservoir which is always placed higher than the town, and is often covered in. (In the absence of light many kinds of smaller plant-life which would contaminate the water will not grow.) Water always finds its own level, so that when the storage reservoir is situated at a higher altitude than the town, water

will flow naturally to each part of the town and to the top of the highest buildings. To ensure this, in flat districts, high water-towers are built and the water is mechanically pumped into the large tank at the top of the tower and from thence it flows naturally to the various parts of the town. This high position of the reservoir or tank also ensures a high pressure of the water supply which was calculated (page 39) to be 56 lb. per square inch for each 100 feet difference in level. That calculation assumed no loss in pressure through the water having to force its way through the water mains. The mains which conduct the water from the source of supply to the storage reservoir are a few feet in diameter. Usually smaller iron pipes are used to convey the water through the streets to the

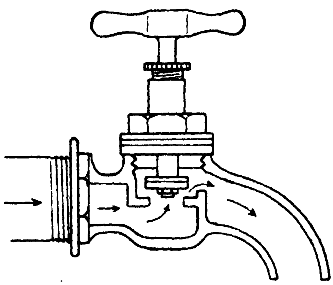


FIG. 174

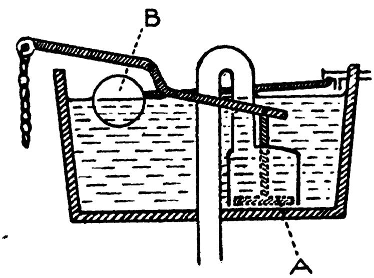


FIG. 175

buildings. At certain places water valves and taps are placed so that, if need be, the water can be cut off from certain areas. At other places fire hydrants are fixed.

Water rushes out of the tap (the action of which can be seen in Fig. 174) because of the pressure of the supply in the mains. Water for the use of water closets is stored in a small tank (Fig. 175). The pulling of the chain lifts the plunger, A. This forces some of the water up the tube, so filling the bend. The water in the tanks then siphons over, so emptying the tank. Meanwhile the ball at B falls, the tap automatically comes into action and water enters the tank from the service pipe until it becomes full, for as it becomes fuller the ball rises and in time closes the tap.

THE GAS SUPPLY OF A TOWN

Coal is not a chemical compound but is a mixture of many substances and contains the elements carbon, hydrogen, oxygen, nitrogen and sulphur. When it is burned in an open grate

oxidation takes place with the formation of carbon dioxide and water vapour together with smoke, ashes and other products (see page 209). Entirely different substances are obtained when coal is heated in an oven-like structure, called a retort, at the gas works, in such a way that air cannot get to it, for then oxidation does not occur. A soft or bituminous coal is used and the process is known as one of destructive distillation. The coal is placed in the retorts (Fig. 176) and heated to a temperature of over 1,000° C.—to a bright, cherry red colour—usually by means of producer gas (page 184). After about twelve hours the coke which is left is pushed out and cooled and a new supply of coal is added. The coal gives out a thick brown smoke which contains the coal-gas and which is first

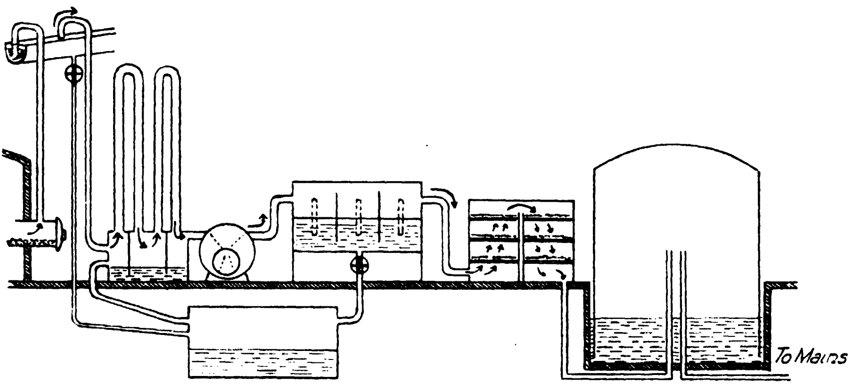


FIG. 176

passed into the hydraulic main containing water. The gas is cooled a little with the result that some tar and ammonia condense out of the "smoke." Furthermore, the water in the main acts as a seal preventing the gas from passing back into the retorts. The "gas" is still very hot and must be cooled. This is done by passing it through the condenser, where it is water-cooled and more tar and some light oils separate out. It is then pumped through "washers," some types of which are rotated by machinery. These contain water which is swished round and mixed with the gas. The water dissolves the ammonia, which is very soluble, and any tar which has not been previously extracted is deposited. All the tar produced, i.e. that in the hydraulic main, in the condensers and in the washers, is led to a tar and liquor well where the heavy tar separates from the water and sinks to the bottom.

The main impurity which now remains is hydrogen sulphide and this is removed in the purifier by passing the gas through iron oxide or slaked lime. Finally the gas is passed for storage into the gas-holder.

The composition of coal-gas varies, being approximately:

Combustible Gases.		Non-combustible Gases.	
Hydrogen . . .	50 per cent.	Oxygen	less than 1 per cent.
Methane . . .	30 ,, ,,	Carbon Dioxide	,, 1 ,, ,,
Carbon Monoxide	10 ,, ,,	Nitrogen .	about 5 ,, ,,
Illuminants . .	3 ,, ,,		

OTHER PRODUCTS FROM THE GAS WORKS

Coke.—Each ton of coal leaves about 13 cwt. of coke, some of which is used to heat the retorts and the rest mainly as a fuel, e.g. for houses, greenhouses, schools and churches, bakers' ovens and so forth.

Ammonia.—The ammoniacal liquor is heated by steam-pipes, occasionally lime being added to it. Ammonia gas is given off which is then led into sulphuric acid to form ammonium sulphate.

Ammonia + Sulphuric Acid = Ammonium Sulphate.

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$

This is a very valuable fertilizer supplying the plants with the much needed nitrogen. If the ammonia gas is passed into hydrochloric acid the product is ammonium chloride or sal ammoniac which is used in medicines, in electric cells and some industries (galvanizing, calico printing).

Coal-Tar.—Many years ago gas-tar was of little value; now numerous substances are obtained from it by first distilling it and collecting the distillate at different temperatures. The residue is pitch. The distillate yields many compounds of carbon and hydrogen including benzene, toluene, naphthalene, creosote, naphtha and carbolic acid. Benzene can be converted into aniline, which is the starting chemical of a large number of dyes; toluene is used in making the explosive T.N.T. (page 197), and is also used in dye manufacture. Naphtha is used as a sovlent for paints and varnishes and in grease and oil removers. Creosote is used for preserving timber and for making sheep dips and disinfectants. Phenol or carbolic acid is used in the manufacture of picric acid and has numerous other uses, e.g. in the manufacture of bakelite.

The Supply of Gas to Consumers.—The gas companies, besides having to ensure the absence of chemical impurities in the gas, are required, by law, to declare the heating value of the gas and to supply it at a sufficient pressure.

Calorific Value of Gas.—A special kind of calorimeter is used at the gas works to determine the calorific value of the gas. A small stream of water passes through a meter which measures the volume passed through. This enters the calorimeter and its temperature is recorded. It then circulates round a chamber in which gas is burning and then out of the calorimeter, its temperature on leaving being recorded. Thus the increase in temperature of a known volume of water, and hence a known weight, is found. Another meter measures the volume of gas which has been burned while the water was in the calorimeter. Assuming that one cubic foot of gas has been burned, that 30 lb. of water has passed through, that the temperature of the water on entering was 50° F. and on leaving 65° F., then the gas has a calorific value of $30 \times (65 - 50) = 450$ B.Th.U. per cu. ft. (page 80).

Pressure of Gas.—According to law, gas must be available at not less than 2 inches pressure of water in pipes of 2 inches diameter and upwards. The pressure of gas is of great importance for reasons given later. The gas is compressed in the gas-holder and is distributed through large mains and then through smaller service pipes. It is an easy matter to test this pressure at any point by attaching the **U**-tube (Fig. 177) to the pipe. Before the tap is turned on water is put in the tube so that it is about half-way up each limb and the tube is clamped in a vertical position. When the tap is turned the pressure of the gas forces the water down in the nearer limb and up in the other, and the difference in level registers the pressure.

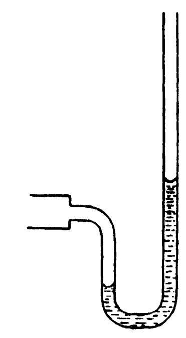


FIG. 177

Gas for Lighting.—A naked gas flame gives out very little light compared with that emitted from a mantle. Gas mantles are made of knitted or woven cotton or silk material dipped in a solution of 99 parts of thorium nitrate and 1 part of cerium nitrate. The material is then moulded to shape and the finished mantle dipped in collodion to prevent breakage in transport. It is put in place on the burner and lighted, the collodion burns off and the nitrates are converted into thorium and cerium oxides.

The burner is similar to the bunsen-burner, and if the pressure of the gas is sufficient the gas emerging from the pipe draws in air through the air-holes so that there is complete combustion as in the bunsen-burner (page 183). The heat makes the oxides white hot or incandescent and so provides the light.

Gas for Cooking.—An ordinary gas-ring consists of a number of openings all coming from a common tube which has an air inlet. As in the bunsen-burner, the gas is supplied at a pressure and in rushing up the tube draws in air so that the gas is burned to water and carbon dioxide. The bottom of the vessel, e.g. the kettle, is heated by contact with the flame and hence it is wasteful to turn the gas so high that some of the flames do not touch the metal. The heat passes through the metal by conduction into the water at the bottom, convection currents are then set up (page 89) and in time all the water becomes heated by convection.

The Gas Oven.—The oven is heated by means of two tubes with jets, one at each side at the bottom of the oven. Once again, the principle of the bunsen-burner is used so that all the gas is burnt. The air at the bottom of the oven is heated and convection currents are set up, but the bottom is always the hottest place.

Many ovens are fitted with thermostats (page 7) which can be regulated to give a few different but constant temperatures. It is obvious that the walls of the oven become hot, and if they were made simply of sheet metal some of the heat would be conducted through the metal and then radiated into the room. To prevent such a loss of heat the outer walls are lagged, that is, two layers of metal are used, the inner space being filled with a non-conducting material.

Many ovens are fitted with a toasting grid which is heated directly by the gas, when it becomes red hot. The bread, etc., is put a little distance below it and is heated by radiant heat, more or less uniformly.

Gas Fires (Fig. 178).—The tubes at the bottom of a gas fire well repay inspection, the one leading in the gas is a small one, closed at the end except for a small hole through which the gas rushes out at considerable speed. The outer tube does not touch this, indeed there is an air gap through which air is drawn. It is, in principle, a bunsen-burner. The outer tube bends round and has a number of jets at its upper surface. When the gas is set on fire from these jets it burns with a non-luminous flame, but such a flame is a poor radiator of heat. Hence, over each jet is

placed a piece of firebrick moulded and shaped as shown. These pieces, known as radiants, become red hot and warm the room by radiation. The radiants are placed against a firebrick backing which also becomes hot and has good radiating properties.

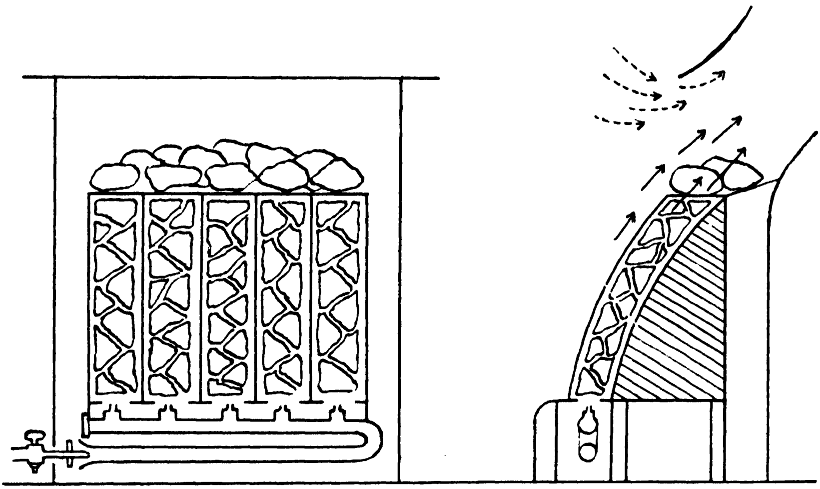


FIG. 178

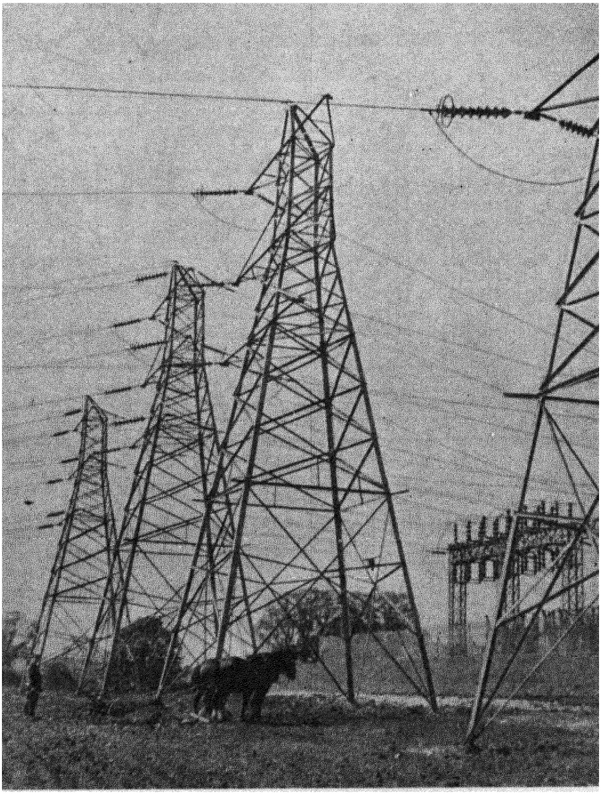
This backing has a rough, corrugated surface, so giving a greater radiating area than it would if it were smooth. The products of combustion, carbon dioxide and water, pass up the flue. These warm ascending gases create a draught, and some of the air of the room is drawn up the flue, so helping to ventilate the room.

THE SUPPLY OF ELECTRICITY

In 1926 a national scheme was set up and the Central Electricity Board is now responsible for the generation and transmission of electricity. A few large generating stations are now at work and they supply electricity, by means of the "Grid," to most parts of the country. It is transmitted at voltages as high as 132,000 volts by the familiar wires on pylons (Fig. 179). These wires are bare since the thickness of the insulated covering which could be used would be entirely ineffective at these voltages in preventing a short circuit should, for instance, two wires touch. The insulation between the wires is provided by the air and at the pylons the wires are suspended from porcelain insulators. Where the lines must be taken underground they consist of cables which are very expensive

to produce as the insulation must be very thick at such high pressures.

The current is an alternating one having a frequency of alternation of 50 a second. This is called a 50-cycle or 50∼A.C. supply. The



Courtesy of Central Electricity Board

FIG. 179

Transmission Lines—showing Pylons and Insulators

frequency is maintained so exactly that electric clocks which are worked from the mains keep accurate time.

The voltage of 132,000 is used for the transmission over the longest distances and this voltage is then reduced by means of transformers for further transmission over shorter distances, 66,000, 33,000, 11,000, 6,000 and 3,000 volts being used according to the length of the line. The power transmitted by means of the lines

depends on the product of the current and the voltage. At a high voltage a greater power can thus be transmitted over the same line and with the same current than when the voltage is low. The wiring system cannot take satisfactorily more than a certain current (about 1,000 amps per square inch of the section).

The electricity is supplied to the houses at 230 volts by two leads, a " live " one and the earth wire or " neutral." The latter is connected to earth by the supplier and there is practically no voltage between this wire and earth. There is, however, the full supply voltage between the live wire and the earth so that when the live wire is touched a shock is experienced since the current passes through the body to the earth.

The electric wiring in buildings connected to these two wires is insulated with rubber and either enclosed in a steel casing or conduit or else sheathed with a lead alloy. The surrounding metal, whether lead or steel, is electrically connected throughout the building and is earthed usually to a cold-water pipe. This prevents the casing from becoming " live " in the event of insulation breaking down. It also provides an earth connection for appliances such as electric fires which usually have their exposed metal parts earthed.

In house wiring the leads from the live side of the mains are usually distinguished by being covered by red insulation and those connected to the earth side (or the neutral wires) with black. A diagram showing the wiring of a house is given in Fig. 180, the live wires being shown in thicker lines than the earth wires.

The main leads go first through the company's fuses, which are usually sealed, and then into the meter, which registers the total number of units used. When the house is wired for lighting, for a cooker, and for heating or " power," leads go to separate switches and fuses (Fig. 181) for each supply and then to the various circuits which are described later. These separate circuits are necessary since different thicknesses of wire have to be used, the thickness depending on the current passing through it. Heat is generated owing to the resistance of the wire and if the wire were too thin the heat produced might rapidly destroy the insulation when the current is passed along it. Thus it is necessary to calculate the maximum current which will be carried by a particular wire. If there are, say, six 100-watt lamps on a circuit the maximum current will be :

$$\text{Amperes} = \frac{\text{Watts}}{\text{Volts}} = \frac{600}{230} = 2{\cdot}6.$$

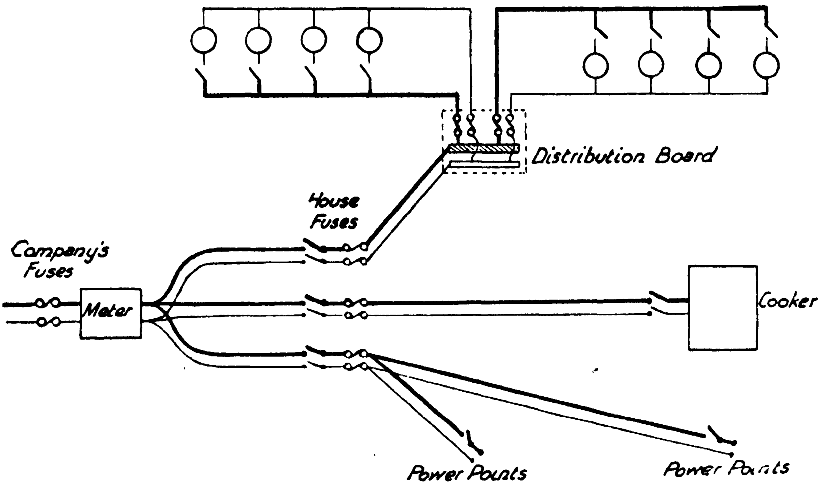


FIG. 180

Actually the wiring for electric-lighting circuits is of five-ampere size. But electric fires take a greater current, e.g. a three kilowatt fire takes $\frac{3000}{230} = 13$ amperes and the wiring for heating and power circuits is often of 15 ampere size while an electric cooker may take as much as 30 amperes. Hence an electric fire, or similar appliance, should not be connected with the lighting circuit (one of 500 watts might be so connected, however).

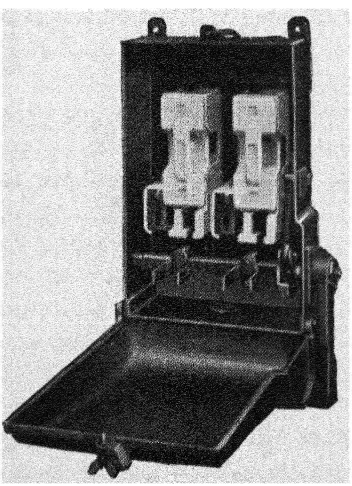


FIG. 181

Fuses.—The heat generated by the passage of electricity along a wire is put to a useful purpose in fuses, which depend for their action on this property. If for any reason there is a short circuit or if the circuit is overloaded the amount of current passing is temporarily greater than that normally provided for. This produces extra heat and but for the fuse much damage might be caused to the wiring. Fuse wire is usually made of thin tinned copper wire and the greater heat momentarily generated melts it and so the circuit is broken. It follows from

the foregoing paragraph that suitable " fuse " wire must be used. Thus 5-amp. fuse wire is used for the lighting circuit and 15-amp. wire for the power circuit. The company's main fuse is their concern and must not be touched by the consumer.

Switches.—Again, switches suitable for the circuit must be chosen. The main switches are of the double-pole type and break both connections to the main when switched off. The switches normally used in lighting circuits are of the single-pole type and are always placed on the live side of the mains.

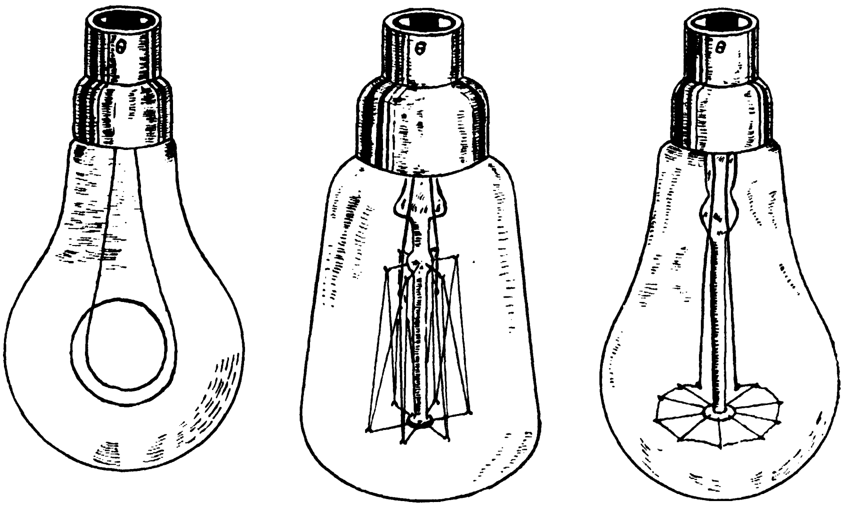
Lighting Circuits.—When more than one lighting circuit is required in a house the leads to each are taken from a distribution board. The two wires from the mains are connected to separate bars of metal, called bus bars, from which each circuit is fed, through separate fuses. The " live " bus bar is shown shaded in Fig. 180 and the live wire in a thicker line than the earth wire. It will be noticed that the switch is placed on the live wire side of the lamp. A number of lamps in parallel are shown on each circuit.

Electric Lamps.—Electric lighting by incandescent lamps dates from the invention of the carbon filament about 1880, the pioneers of its development being Edison in America and Swan in England. The bulb was exhausted of air otherwise the heated filament would be acted upon by the air and also heat would be lost by convection currents. A later type of carbon filament lamp is shown in Fig. 182, A. Nowadays the filament is made of the metal tungsten. The vacuum type of metal filament lamp is shown in Fig. 182, B, which has largely been displaced by the type shown in Fig. 182, C. This lamp has a tungsten filament in an inert gas such as nitrogen or argon. This enables higher filament temperatures to be maintained by tending to prevent the volatilization. In addition, the particles produced in this way are carried upward by convection in the gas to the cap and do not blacken the bulb where most of the light passes through. In these " gas-filled " lamps the cooling effect of the convection currents is reduced by the use of a coiled or spiral filament which gives as small a contact as possible with the gas. Recently improved efficiency has been obtained by using a double coiling in lamps of lower power where the filament is necessarily long.

To eliminate glare from the brilliant filament of a gas-filled lamp the bulbs are frequently frosted internally by sand blasting to diffuse the light (page 101). These are pearl lamps; opal lamps have a thin coating of opal glass on the outside of the clear glass bulb.

In modern lighting use is made of many different kinds of shades, which are often designed to prevent glare and to diffuse the light. In direct lighting a shade is used to reflect the light downwards. In semi-indirect lighting, such as with bowl shades, part of the light is passed directly through the translucent shade and part diffused from the ceiling. Sometimes all the light is arranged to be diffused from the ceiling or walls, but this is only efficient when the surface has a high reflecting power.

The number of watts taken by a lamp divided by its candle-power



A B C

FIG. 182

gives the efficiency of a lamp, the lower its value the more economical is the lamp in running cost. A gas-filled or "half-watt" lamp has an efficiency of about 0·5 watts per C.P., but this is only for the higher powers, such as 100 watts and upwards. Lamps of lower power take from 1 to 0·7 watts per C.P., though the coiled coil type of filament increases the efficiency by about 20 per cent. for the smaller sizes.

The efficiency of lamps in use decreases with age, about 1,000 hours being the normal useful life. Dust on lamps and their shades may also seriously reduce the light obtained if it is allowed to accumulate.

Electric Fires (Fig. 183).—The heating element consists of a spiral of metal wire of material such as nichrome, an alloy of

chromium and nickel, which besides being of high resistance is not readily oxidized and so can withstand the heat. Several elements, each taking a kilowatt, or a simple fraction of one, are frequently arranged in parallel so that one or more may be cut out by a switch when not required. The fire-bar type of electric fire has resistance wire which is coiled and wound in grooves in the surface of a slab of fire-clay. A few minutes after switching on, not only does the wire itself radiate heat, but also the fire-clay behind it.

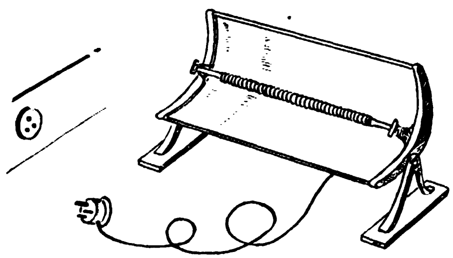


FIG. 183

The reflector type of heater has the heating element at the focus of a parabolic reflector of polished copper or brass. This may be of bowl shape with the resistance wire wound on a short tube, or shaped like a trough, when the element is rod shaped. In both types practically all the heat is reflected and is localized into an almost parallel beam. All the heat produced by an electric fire can be made to warm the room as there are no products of combustion to be removed as in the case of gas or coal fires.

Usually the plugs connected to heaters are of the three-pin type, the third pin being connected to the metal frame of the fire. The socket in which it fits makes connection to the earth through the metal or lead casing covering the cable. Hence the danger of the metal work of the fire becoming " live " when there is a breakdown inside is diminished.

Cooking by Electricity.—The oven used in an electric cooker contains heating elements which provide altogether about 1 kilowatt for each cubic foot of oven space. There are usually three switch positions for the heaters, which are marked " Low," " Medium " and " Full," more elements being connected in parallel when greater heat is required. Thermal insulation is often provided by a lagging of asbestos wool between the oven itself and the frame of the cooker as in the gas oven. There are no products of combustion to be removed and no air has to be supplied for burning. Almost all the heat supplied is usefully employed.

Electric cookers are usually provided with hot plates which are used for boiling and frying. A hot plate consists of one or more

coils giving their heat to a flat plate of iron which becomes red hot. Hot plates are not very economical compared with other methods of heating, particularly when the bottom of the pan used is not flat and so does not make good heat-conducting contact with the hot plate. Pans and kettles containing heating elements are much more economical because the heating element is surrounded by the liquid to be heated.

The metal frame of an electric cooker is always earthed so that there is no chance of it becoming "live" by contact with any defective wiring. The same house wiring is not employed for a cooker as for the lighting or heater circuits, high current capacity cable being brought to the cooker direct from the mains supply (page 223).

Electric Motors (page 147).—Electric motors are used in the home in vacuum cleaners, electric washers, refrigerators, and sewing-machines. They are all fractional horse-power motors. Frequently they are of the universal type and can be run from either A.C. or D.C. supplies, the field and armature being in series. Care is needed in oiling that no oil gets on the commutator where the brushes pass the current into the armature. The brushes are made of carbon and need occasional renewal. Another type of motor, the induction motor, which only runs off A.C. supplies, is sometimes used in refrigerators and washers. The armature currents are induced by the varying currents in coils on the fixed part of the motor. Consequently there are no brushes or commutator, and the machine is very reliable.

Vacuum Cleaners.—The fact that dust and dirt can be carried in the air is actually the principle on which the vacuum-cleaner depends. The air in contact with the carpet is drawn into the cleaner, carrying the dirt with it. The action is caused by a fan inside the machine which is driven by a motor and causes a partial vacuum inside the machine. The air is filtered as it passes through the material of a bag, and out of the machine, leaving the dust and dirt behind.

CHAPTER XXIV

ENERGY

THE fruitless quest for the philosopher's stone by the alchemists in the Middle Ages has a parallel in the attempts to solve the secret of perpetual motion. The idea was a very attractive one, namely to design a machine which would do work without being driven itself and without being supplied with anything corresponding to fuel or heat to work it. Nowadays we recognize the impossibility of making a machine to act in this way, because in order to do work all things, including machines, need energy which is supplied by the fuel, heat, electricity, etc.

Previous to the development of the steam engine, largely due to James Watt, the only supplies of energy available to work machines or for transport were much the same as they had been for centuries. The energy or power of the wind was harnessed to drive along the sailing ship and to turn the windmill for grinding corn. Water-wheels also were used for grinding corn and to work machines of various kinds. But most machines had either to be worked by hand or by animal power. The horse began to be displaced early in the nineteenth century as the first steam locomotives were introduced for land transport, but it is only a matter of a generation or so ago that the further displacement of the horse started with the introduction of the petrol engine.

Steam Engines.—A simple double-acting steam engine is shown in Fig. 184. Steam generated in the boiler at a high pressure is led into the steam chests and, with the piston in the position shown, enters the cylinder through the left hand port A. As the steam leaves the boiler more is generated to take its place, each cubic inch of water changing into many times its own volume of steam. The steam as it enters the cylinder pushes the piston some distance to the right. But this movement causes the sliding valve to move to the left until it covers port A. This first part of the movement is consequently due to the full pressure of the steam as

it comes from the boiler. The stroke is then completed by the expansion of the compressed steam in the cylinder.

While the piston is moving, the steam which produced the previous stroke from the other end of the cylinder escapes through the right hand port B and out of the exhaust C. The ports are opened and closed at the proper times by means of a sliding valve, V, connected by a rod to an eccentric on the crank-shaft. Port A is open to the steam as the piston starts moving to the right and B to the exhaust, while in the reverse stroke, B is open to the steam and A to the exhaust, and the steam first moves the one piston one way and then the other, causing the main shaft to turn by means of a crank.

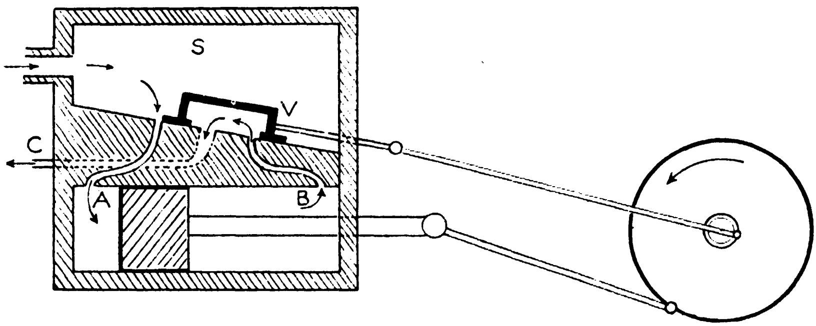


FIG. 184

In some engines the steam expands successively in several cylinders, each larger than the one preceding it, and the steam does work in each stage, e.g. a triple-expansion engine in which there are three cylinders.

In the De Laval steam turbine, steam under pressure escapes at a high speed through jets and impinging on the blades of a wheel causes it to rotate. The Parson's turbine has a series of such moving wheels connected together on the main shaft and separated by fixed blades. The steam entering the turbine passes in turn between fixed and moving blades and strikes the blades obliquely. After being deflected in one direction by the moving blades on one wheel it is deflected in the reverse direction by the fixed blades so that it again impinges obliquely on the next set of moving blades in such a manner as to give the same direction of movement as before. Steam turbines are used in the generation of electrical power.

The Petrol Engine.—A different kind of engine is used when petrol, gas and heavy oils are used to supply the energy. The combustion of the fuel takes place inside the cylinder and the engines are known as Internal Combustion Engines. The four operations in a four-stroke petrol engine are illustrated in Fig. 185.

First stroke (the suction stroke). The piston moves towards the crank-shaft, and the pressure of air in the cylinder becomes less than that of the atmosphere. Petrol and air mixed in the carburettor are forced in through the inlet valve, which is opened by a cam.

Second stroke (the compression stroke). The piston moves upward towards the cylinder head and compresses the mixture of petrol vapour and air, both the inlet and exhaust valves being closed by the action of their cams.

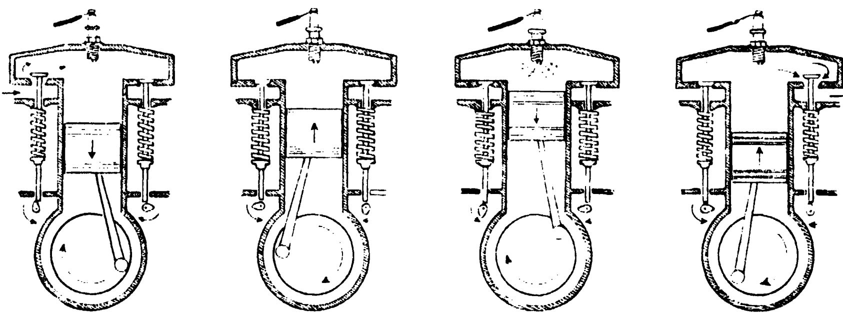


FIG. 185

Third stroke (power stroke). A timing mechanism causes a current of electricity to pass to the sparking-plug and a spark is produced. The gases explode and in this chemical action the petrol is oxidized and heat is evolved which causes a rapid expansion of the gases. The pressure is thereby increased and both valves being closed the piston is forced downward to the crank-shaft, moving the flywheel round.

Fourth stroke (exhaust stroke). The momentum of the flywheel carries it round and forces the piston upwards towards the cylinder head. The cam actuates the exhaust valve, causing it to open, and the products of combustion are forced out through this valve into the exhaust pipe.

Such an engine has to be started by turning the engine over either by hand or by an electric motor. Much heat is generated during the combustion of the gases and the cylinder walls would

become too hot for lubrication to be effective were they not cooled by water. Water has a great capacity for heat (page 83) and the hot water is led to the radiator where it is cooled by the cold air, a circulation being maintained by convection.

The Diesel Engine is another type of internal-combustion machine and is also a four-stroke type. Air is drawn into the cylinder at the first, or suction, stroke. The second stroke compresses this air and thereby raises its temperature. At the end of the compression heavy oil is squirted into the heated air by means of a pump and rapid combustion takes place immediately since the temperature of the air is sufficiently high to ignite the oil spray. Consequently no spark is necessary. The oil is burned and the heat of chemical action causes the gases to expand. The power stroke is then completed, followed by the exhaust stroke as in the petrol engine.

FORMS OF ENERGY

Potential and Kinetic Energy.—The weights of a grandfather clock gradually lower and in doing so turn the mechanism which runs the clock. They are then doing work in overcoming the resistances to the movement of the various parts. The weights do work in falling and so have energy due to their position above the ground. This energy is called potential energy or energy of position. As they descend, doing work as they move, they are said to expend their energy. When they are at the bottom, the clock must be wound up and work is then done in raising the weights and in so giving them potential energy.

It is similar with a moving object. Work is needed to set it moving and it does work as it comes to rest against resistances to movement such as friction. The energy of a moving object is called kinetic energy. It is the kinetic energy of the head of a hammer as it strikes a nail which is expended in driving the nail into the wood. Kinetic energy is expended as a moving object is brought to rest.

Air compressed in a cylinder has energy, for it can do work. For instance, it may be used to work a road drill. A wound-up clock spring has energy similar to that of compressed air and this form is often called energy of strain, though it may be classed with potential energy.

Energy, whether potential or kinetic, can be measured in foot pounds from the work which is done in giving the energy or the work given out when the energy is expended. Thus a 10 lb. weight

raised vertically through 5 feet needs 50 ft. lb. of work to raise it and has 50 ft. lb. of potential energy, which it can give out in falling. In falling freely it changes into an equivalent amount of kinetic energy which may be changed back into potential energy, as when the weight swings like a pendulum, falling a certain distance and rising almost the same amount on the other side. The gradual loss of height and of speed as an object swings from side to side is caused by friction. Energy is gradually "lost." It is the same with a machine, the work got out is less than that put in because energy is expended in doing work against friction inside the machine.

When there is friction between two surfaces heat is always produced as one slides over the other. The greater the amount of work done against friction the greater is the amount of heat produced and there is a definite quantity of heat produced for each foot pound of work. Thus 778 ft. lb. of work produces 1 B.Th.U. of heat. This was first found by Joule who turned a vane in water by means of a falling weight and the vane churned up the water and heated it. He then calculated the amount of heat given to the water (from its weight and the rise of temperature produced) and also the amount of work done (from the product of the weight and the total distance moved through by it in falling). He was then able to calculate the work in foot pounds needed to produce 1 B.Th.U. by friction.

Heat can be used to do work. For instance, in a steam engine a certain amount of coal must be burned to give a certain amount of heat which is needed to do the work required to run the engine. Measurements show that some of the heat given to the steam is not recovered when the steam is condensed. Some of it has disappeared—actually 1 B.Th.U. for each 778 ft. lb of work done by the engine. These facts indicate that heat can be classed as a form of energy which can be transformed into other forms.

Chemical Energy.—Many machines get their energy from the fuel which they burn, the energy being liberated as the result of chemical change. The petrol of a motor-car undergoes a chemical change with the air, and the energy is liberated both as heat and as mechanical energy, i.e. the energy required to work the machine. There is a relation between the quantity of petrol used and the work got out of it. The heat which can be obtained from a fuel gives a measure of the energy which is liberated when the fuel is burnt. Thus the calorific value of a fuel indicates the energy which can be obtained from it. The proportion of this energy which is

changed into mechanical work is usually rather small and gives a measure of the efficiency of the engine. Much of the energy is dissipated as heat and it must be removed, as it is in the radiator of a motor-car or the condenser of a steam engine. A steam locomotive only uses about 4 per cent. of the energy of the coal though a modern steam turbine has an efficiency of up to 30 per cent. Living things are engines in the mechanical sense. The food they eat, on combining with oxygen, gives them energy. The heat value of the food (p. 264) is calculated in Calories and the proportion of energy obtained from the food (glycogen) used in doing work may be found—it is sometimes as high as 25 per cent.

Electrical Energy.—Electricity is a form of energy, capable of being converted into the other forms. Thus electricity produces heat, light, chemical action, mechanical work and it may be produced by these forms of energy. There is a definite relation between electrical energy and, for instance, the heat or work it produces, e.g. one unit of electricity produces 3,450 B.Th.U. of heat; 746 watts of electrical power produce 1 h.p. of mechanical power in a motor, while in a dynamo 1 h.p. of mechanical power produces 746 watts of electrical power.

Radiation.—Light and radiant heat are forms of energy. When they are absorbed heat is produced. Plants use the energy from sunlight to make their food (p. 293), and this process is of the first importance. Animals obtain their food, directly or indirectly, from plants, and hence get their energy from the sun. Coal, when burnt, supplies energy which came from the sun many thousands of years ago when the plants from which it was derived were growing. The energy of the wind is derived from the sun, for it is the sun's heat which causes the convection currents by which the air moves. The sun's heat causes the evaporation of water on the earth and the air currents carry the water vapour upwards to form clouds. The water falls later as rain. So streams and rivers also derive their energy from the sun.

Consequently it is the sun which supplies the energy for practically all the activities and movements on the earth. An interesting exception is provided by the tides. Their energy comes from that of the rotation of the earth and the earth in consequence is gradually slowing down.

Conservation of Energy.—Energy is indestructible; when one form appears another disappears in corresponding amount. This is called the principle of the Conservation of Energy. On the other

hand all energy tends sooner or later to result in the production of heat by friction and similar means. Heat is a form of energy which is not always capable of being changed back into other forms. This is why fresh supplies of energy are all the time needed to keep up the movements and activities of the world around us.

CHAPTER XXV

EXTERNAL FEATURES OF PLANTS

GROUNDSEL is one of the commonest plants to be found in this country. Each plant has a succulent, juicy stem which is continuous below ground with a main root which has many branches. The stem bears a number of leaves which are very coarsely toothed and which, when full grown, have practically no stalk. The swollen part of the stem at the point of attachment of a leaf is termed a node, the region between two nodes an internode. In the axil of each leaf, which is the acute angle between the leaf stalk and the stem, is a branch which has arisen from a bud. The buds at the tips of all the branches grow into yellow flowers, each of which produces many fruits. Each fruit has a number of silky hairs attached to the upper end and is carried by the wind to a considerable distance from the parent plant. The fruit contains a single seed, which is capable of growing into a new plant in suitable conditions. Groundsel is so abundant because it grows very quickly and passes through its complete life history in such a short time that several generations are possible in a single year. It is a great nuisance to farmers and to gardeners and can

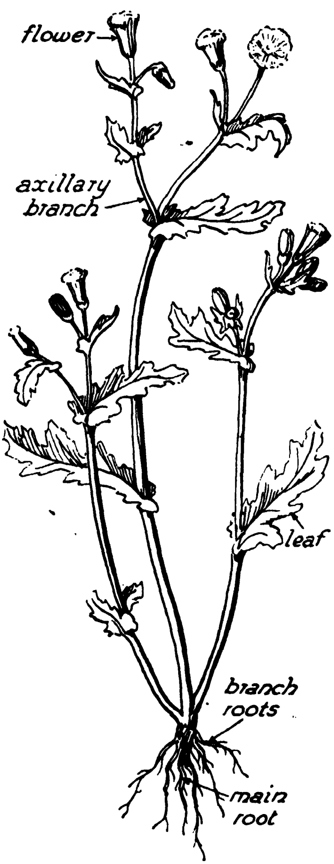


FIG. 186

only be kept down by repeated hoeing. Groundsel is, of course, widely used as a green food for cage birds.

Functions of Plant Organs.—The stem is erect and bears leaves and flowers, which are arranged in various ways in different plants. Sometimes the leaves are arranged in pairs, the points of attachment being exactly opposite one another, but the usual arrangement is in the form of a spiral. The leaves, which are primarily feeding organs, are arranged in such a way that each leaf receives the maximum amount of sunlight. The root system serves to anchor the plant, and also provides the mechanism for the absorption of water and other materials from the soil.

Modifications of Structure. (*a*) **Spines.**—It is quite easy to recognize the root, stem and leaves of groundsel, but in many plants these organs have changed considerably in external appearance owing to their modification for such purposes as storage of food, as spines for protection against animals, for climbing, for reproduction and for many other functions. In such cases various clues to the nature of these organs remain, and the puzzle can usually be solved by observing the simple rules that only stems bear leaves and buds, and that anything arising in the axil of a leaf must necessarily be a branch. Thus the spines of the hawthorn are seen to be modified branches in the axils of leaves, while those of the gooseberry are below individual leaves and are actually outgrowths of the base of the leaf-stalk. The stouter spines of gorse are modified branches, but the leaves in this case are also spiny. That the spiny " leaves " of Butcher's Broom are not really leaves is made clear by the fact that each bears a flower in the axil of a tiny scale leaf. The leaf in this case must therefore be a flattened stem.

(*b*) **Climbing Plants.**—The organs by means of which climbing plants grasp supports vary very widely in different plants. Sometimes, as in the honeysuckle, bindweed and the hop, the main stem twines round the support. In other cases grasping organs known as tendrils are produced from various parts of the plant. In peas and vetches the tendrils are modified leaves or parts of leaves, but in the Virginia creeper the tendril represents a terminal portion of the main stem, growth in length being continued by the growth of an axillary bud. In clematis it is the leaf-stalks which twine round other plants in the hedgerow. Plants such as brambles and goose grass which grow over and cling to other plants in hedgerows by spines and small prickles are termed scramblers. Ivy clings

to walls and to trees by tiny roots which grow directly from the main stem and not from the primary root.

(*c*) **Reproduction.**—Most plants reproduce by means of flowers which produce seeds. A flower is actually a modified branch and the various parts of the flower (Chapter XXXVIII) are really modified leaves. Many plants, however, grow from structures which are not seeds, though they can and do produce seeds. Examples are the potato, which is grown from a tuber; the tulip, which is grown from a bulb; and the crocus, which is grown from a somewhat similar structure termed a corm. All these structures are modified stems bearing roots and modified leaves. In each case the plant passes through its life history in a single year and produces a tuber, bulb or corm in addition to seeds. These structures remain in an inactive condition until conditions are suitable for growth and then grow into new plants. In this way the plant reproduces and also passes unharmed through the severe conditions of winter. Thus reproduction is combined with perennation, the survival of plants from year to year.

Bulbs, Corms, Tubers.—The structure of an onion bulb may be examined if the latter is cut longitudinally into two (Fig. 187). As might be expected, leaves, buds and roots are borne by a stem which is here quite small and roughly triangular in this section. On its lower side it bears roots, and on its upper side a relatively large terminal bud, which is surrounded by large, white, fleshy scale leaves, in turn protected by dry, brown scale leaves. In the axils of the fleshy scale leaves are axillary buds which may develop in suitable conditions. If the bulb is dissected or cut transversely, it will be seen that each fleshy scale leaf forms a complete circle and that all have the same centre. When the bulb germinates in the soil, the terminal bud elongates and the stem to which it gives rise pushes its way above the surface of the soil and produces foliage leaves and flowers. The reserve food stored in the fleshy scale leaves is gradually used up as the terminal bud grows and eventually the old bulb withers away. Meanwhile, the leaves of the new plant are being active and food material is being passed down the stem. One of the axillary buds now begins to develop into a structure exactly similar to the old bulb, and the food accumulates in the fleshy leaves of the new bulb. When the plant dies, a new bulb has thus been formed on the withered remains of the old bulb. In fact several new bulbs may be formed in this way from axillary buds. The method of formation of new bulbs means

that successive generations will become gradually nearer the surface, and to remedy this some bulbs have special roots which gradually contract and pull the small bulbs down. There are many other examples of plants with bulbs as, for example, tulips, narcissi, hyacinths, and lilies.

Corms (Fig. 187) are very similar to bulbs and are formed in much the same way. The chief difference is that the corm has no fleshy scale leaves, the reserve food being stored in the enlarged

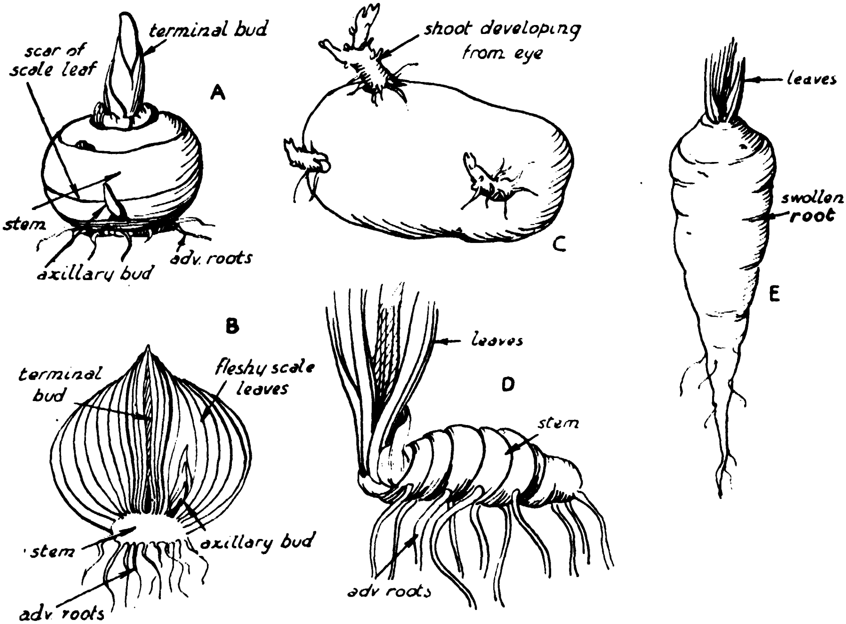


FIG. 187

A, Crocus corm. B, Onion bulb. C, Potato tuber. D, Iris rhizome. E, Carrot.

and swollen stem. The life cycle is much the same as in the case of the bulb, the base of the shoot formed from the terminal bud thickening to form the new corm. Examples are the crocus, montbretia and the "bulbous" buttercup, in which the basal swelling is a corm and not a bulb.

Tubers (Fig. 187) are formed in a different way, but their function is essentially the same as that of the bulb and the corm. When a potato plant has reached a certain stage of development, certain axillary buds grow into long shoots which grow down into the

ground and begin to swell at the tips, thus forming the tubers. The latter are simply modified stems, swollen with food material passed into them from the parent plant. When the latter dies, the tubers remain in the soil, and each is capable of growing into a new potato plant. Each " eye " is a tiny dormant shoot with several buds, each in the axil of a scale leaf, and every bud is capable of sprouting when conditions are favourable. The Jerusalem artichoke is also a tuber produced in exactly the same manner.

Biennials and Perennials.—The structures described in preceding paragraphs are produced by annuals, namely plants which pass through their complete life cycle in a single year. It is not necessary however to plant bulbs, corms and tubers every year if the plants remain undisturbed. Biennials such as the carrot take two years to complete their life history. In the first year the main root thickens and becomes swollen with food reserves, and the plant dies down to this tap root during the winter. In the second year the plant produces flowers and seeds. Perennials last for many years and frequently die down during the winter to a subterranean structure which is usually, as in the lily of the valley, a swollen horizontal stem termed a rhizome. Some plants such as the iris possess a rhizome but retain their leaves during the winter (Fig. 187). Every year sees a growth in length of the rhizome, an increase in the number of shoots from the plant, and an increase in the number of plants if the connection with the parent plant is lost. A number of garden weeds, such as ground elder, twitch grass, and horsetails fall into this category, and it is exceedingly difficult to free a garden from them unless the rhizome is completely removed. The bracken fern has made such strides in this way in recent years that it has become a serious problem in many upland pastures.

Fruit and Vegetables.—Much of our food is derived directly from plants, some from flowers and fruits and some from the vegetative parts. Examples of fruits are apples, pears, plums, cherries, blackberries, currants and grapes. Some vegetables such as peas and beans are actually seeds, the fruits in this case being the pods. Vegetables are, strictly speaking, the leaves, stems or roots of various plants. Examples are the succulent stems of asparagus, the leaves of cabbages, the tap roots of carrots and parsnips, the succulent leaf-stalks of rhubarb, and the bulbs and tubers previously described. Brussels sprouts are very large spherical buds.

CHAPTER XXVI

INTERNAL STRUCTURE OF PLANTS

AS might be expected it was not until the invention of the microscope, nearly three centuries ago, that much advance was made in the investigation of the internal structure of organisms. The scientist Robert Hooke was then responsible for the introduction of the word cell, which he applied to the units which he saw when he investigated the structure of cork under the microscope. The reason was that the units were very regularly arranged, and they reminded him of the cells in a honeycomb. All plants and animals are built up of cells, each consisting of a small quantity of gelatinous material, termed protoplasm, and a distinct structure called the nucleus. In plants the mass of protoplasm is enclosed by a cell wall, which is composed of a substance known as cellulose. The diameter of a normal plant cell varies between 5 and 50 μ, μ being a unit of microscopic measurement representing 0·001 mm. It is quite easy to calculate the diameter of a cell by putting a micrometer scale, that is, a circular piece of transparent material marked like a piece of graph paper, into the eyepiece of a compound microscope, and counting the number of squares which a cell occupies. For instance, the side of one square under the low power objective of one kind of microscope represents 100 μ, and under the high power, 20 μ.

Division of Labour.—It is quite practicable for a few people on a desert island to carry on all the activities necessary for their continued existence individually. Each can, for instance, grow and cook his own food and make his own clothing. This is, however, no longer possible in the British Isles, where over forty million people live within a comparatively small compass. It here becomes necessary to subdivide the population into various trades and professions so that each will be able to specialize in some activity for the benefit of the whole community. Thus, while each individual still eats and wears clothes, the commodities concerned

are supplied to him by special organizations. In other words an adult person leads both an individual and a communal life. The young individual is usually unspecialized, but becomes fitted for some particular piece of work later.

In a similar way some organisms, which are described in Chapter XL, consist of only one cell, or merely of a few cells. In these cases the individual cells are capable of independent existence and carry on all the essential functions for themselves. In more complicated organisms, however, the position is very different and the individual cells which make up a complicated organism are of many types, each with a characteristic structure and a special piece of work to do. The young cells are all alike in the earlier stages but as they become older they become differentiated or modified for special purposes. It is easier to study these changes in plants than in animals since plants grow almost entirely at their tips, whereas growth in animals is not so localized.

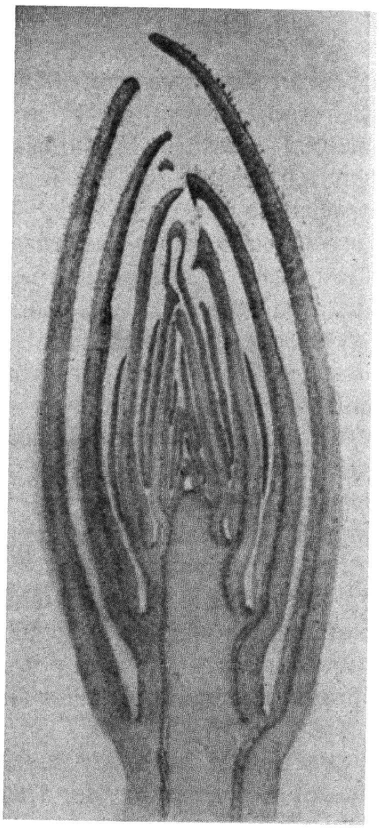


FIG. 188

Longitudinal section of bud of lilac, showing growing point, leaves and conducting tissue

Growing Points of Stem and Root.—The growing points of stem and root are essentially similar, differing chiefly in external features. Thus the apex of the stem (Fig. 188) is enclosed and protected within a bud consisting of young leaves formed from the growing point. The leaves arise on the growing point as superficial swellings which at first grow chiefly on the under side and therefore bend towards the apex. The structure of the growing point of a stem may be determined by dissecting a Brussels sprout which is a very large axillary bud. The leaves gradually

decrease in size as the growing point is approached. In the axils of the older leaves are axillary buds. The apex of the root (Fig. 189) bears no leaves, though it is covered by a root cap which is protective and also plays a part in lubricating the passage of the root through the soil. Branch roots arise from a deep layer of the root. The internal structure of root or stem apex is studied by cutting very thin longitudinal and transverse sections, either freehand by a razor or by some mechanical apparatus using a razor in a steadier manner than would be possible by hand. It has been found that the task of sorting out the various kinds of plant cells in such a section is made much simpler by dyeing or staining the section so that the different types of cell are coloured differently. This is made possible by the fact that different types of cell wall take up different types of stain. The nucleus and the protoplasm can also be shown clearly if suitable stains are used.

The protoplasm, including the nucleus which is a specialized part of it, is the actual living substance of the plant. The cell wall is formed from the protoplasm but is not living. It is the protoplasm which grows and breathes and carries on all the other activities associated with living organisms. It must be remembered that when the protoplasm is seen stained under the microscope it has been killed and subjected to various processes, though it will take up certain stains without being killed. True growth in organisms is dependent upon the formation of new protoplasm, in addition to replacing that broken down in the ordinary wear and tear of life. In plants the necessary food material is conducted to the growing points where the building up of new protoplasm takes place. The cells in these regions are small and cubical, and have a large nucleus. As new protoplasm is formed, these cells are constantly dividing, and the tip steadily increases in bulk. The cell divisions are such, however, that the increase is chiefly in length and subsequent changes in the cells themselves add to this increase. The division of a cell is always immediately preceded by the division of its nucleus in such a way that each new cell has a nucleus. The nucleus must therefore be a very important part of the cell; it does in fact control its activities.

Differentiation of Cells.—The rapidly growing and dividing cells in the growing region of the tip are, as yet, undifferentiated. In a longitudinal section of the terminal part of a bean root various zones in the differentiation of cells can be seen (Fig. 189). The initial stages are due to an increased flow of water into these cells.

The cell wall, which is elastic, is distended by this increase in volume and the result is that the cell increases in length. The amount of protoplasm does not increase, and this stage may be recognized in the section by the clear spaces in the protoplasm, full of fluid.

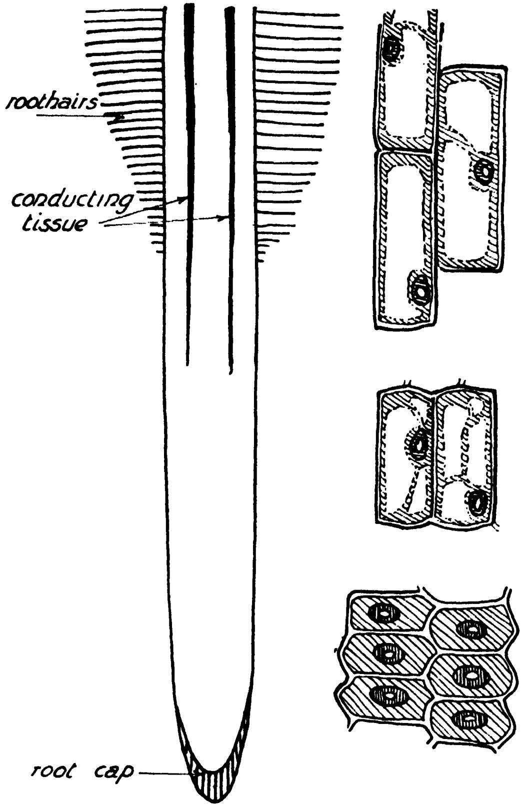


FIG. 189

Longitudinal section of root. The growing point is situated immediately behind the root cap. The drawings on the right illustrate stages in the differentiation of cells in the region of elongation

These spaces are called vacuoles, and eventually they join up to form one large vacuole in the middle of the cell, the protoplasm becoming a thin lining inside the cell wall. Some cells, chiefly those destined for storage and similar functions, remain in this condition. A group of cells all carrying out the same function is known as a tissue, and the type of comparatively undifferentiated

tissue mentioned above is called parenchyma. The cells are, however, sufficiently specialized to have lost their power of division.

The cells which become converted into the conducting tissues undergo drastic alterations. Some become woody, owing to the addition of material known as lignin to the cellulose of their cell

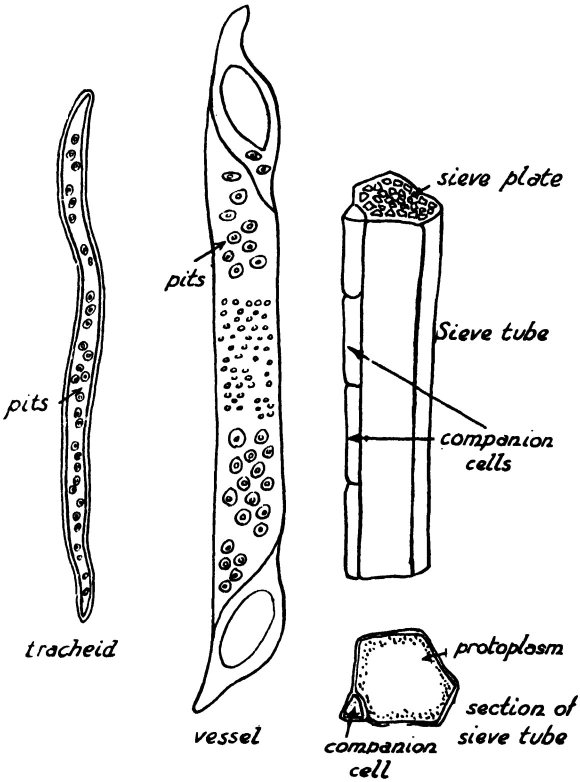


FIG. 190

Tracheid, vessel and sieve tube

After Eames and McDaniels "Introduction to Plant Anatomy," published by McGraw Hill Publishing Co.

walls. Usually some parts of the original cell wall remain unaltered and these parts, known as pits, serve for the passage of water from one element to another. The conducting elements of the wood are termed tracheids and vessels (Fig. 190). The former are small and are derived from single cells which become pointed at both ends and lose their protoplasm. Vessels are long tubes formed from a large number of cells which fuse end to end, and they too

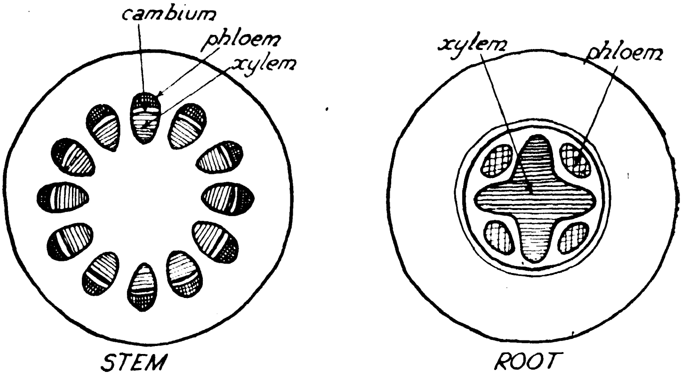


FIG. 191
Transverse sections of stem and root

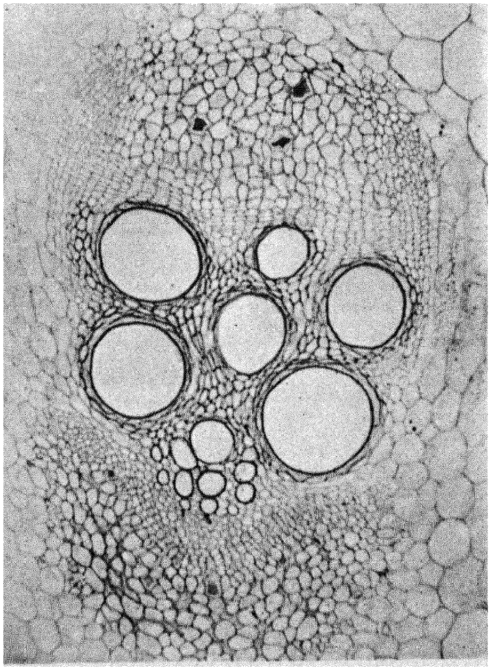


FIG. 192
Transverse section of bundle of Cucurbita, showing xylem, cambium and phloem. Cucurbita is unusual in that phloem is found both outside and inside the xylem

lose their protoplasm. The walls of both vessels and tracheids become lignified in various ways. In the earliest formed elements the lignin is laid down in rings or in a spiral, but in later elements as a network. Other cells become converted into sieve tubes (Figs. 191, 192, 193), which resemble vessels in some ways and have a somewhat similar origin. They retain, however, a cellulose wall and a thin layer of protoplasm just inside the cell wall, but no

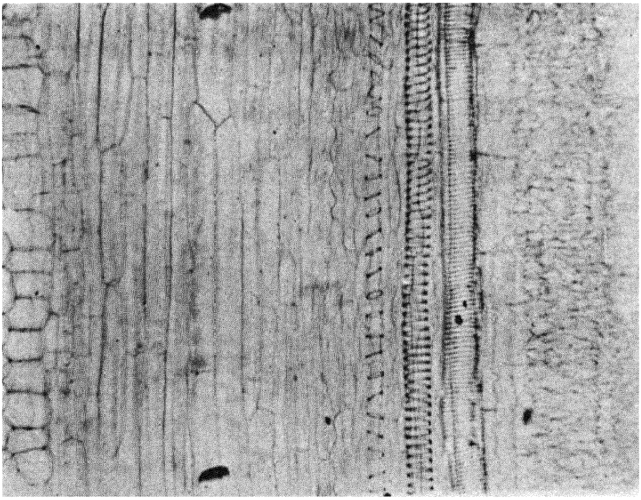


FIG. 193

Longitudinal section of bundle of Cucurbita, showing vessel and sieve tubes. The tranverse black marks are sieve plates

nucleus is present in the mature sieve tube. The protoplasm is thought to circulate slowly inside the tube, thus facilitating the passage of substances from one tube to another through the protoplasmic strands penetrating the sieve plates at each end of the tube. Sieve tubes are usually accompanied by one or more companion cells which are quite normal in structure and possess a nucleus. It is probable that they store food materials. The tissue including vessels and tracheids is known as xylem, that comprising the sieve tubes and companion cells phloem.

Stem and Root.—The distribution of wood and other conducting tissue differs in the stem and root. The root is subject chiefly to forces which tend to uproot the plant, and it must be able to withstand forces acting along it. Consequently, the xylem

and phloem strands are found in the centre of the root, surrounded by a wide band of parenchymatous tissue. The stem, on the other hand, has to resist forces which act at right angles to the direction of its growth, and the xylem and phloem strands are here found near the outside. In the stem, the strands of xylem and of phloem are associated in structures termed vascular bundles, which run longitudinally. Each bundle consists of an outer region of phloem and an inner region of xylem, the two tissues being separated by a layer of still undifferentiated cells termed the cambium. In the root the xylem and phloem strands are not associated and are on different radii.

Herbs, Shrubs and Trees.—Seedlings are able to retain their rigidity in the same way that a heap of footballs would be rigid in that the individual units are distended in the one case by air

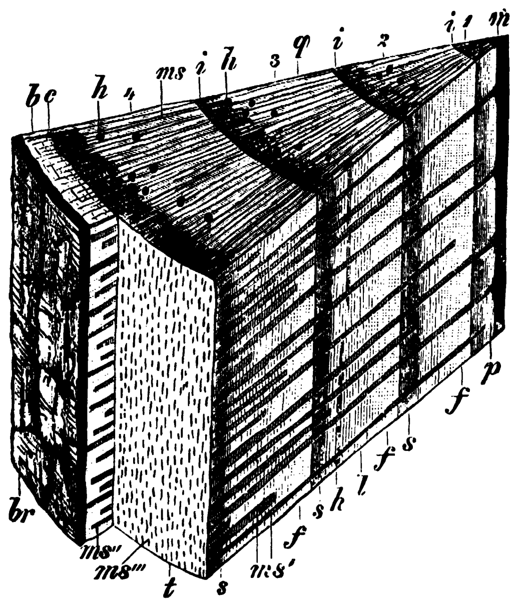


FIG. 194

Portion of a four-year-old stem of the Pine

f, spring wood; s, autumn wood; 1, 2, 3, 4, annual rings; ms, medullary rays c, cambium; b, phloem; br, bark.

and in the other by water. When the vascular bundles have been formed the plant acquires considerable mechanical support, though the primary function of the woody elements is that of conduction. Herbs are plants such as nettles, groundsel and others which have

vascular bundles but which do not look woody. Plants which become woody are termed shrubs or trees. The former are comparatively small and have several main stems of roughly equal importance, the latter are larger and have a definite trunk. In these plants the cambium cells continue to divide and the cells which they produce differentiate into phloem and xylem in such a way that the bundles lose their individuality, and the centre of the stem becomes occupied by a great mass of secondary xylem. In a large trunk the central portion passes out of use and becomes heart wood, the conduction of water being carried on by the outer sap wood. The heart wood is very hard and is used as timber. A section of a twig or trunk of a tree reveals a number of annual rings by means of which the age of the tree can be calculated (Fig. 194). In the winter the passage of water through the xylem stops and the current begins again in the spring. During this period the vessels formed are particularly large and there is a striking difference in appearance between the spring and the smaller summer and autumn vessels. Each annual ring includes a layer of spring vessels and a layer of those formed later in the year.

Bark.—The increase in thickness involves a very considerable stretching of the outer tissues so that the latter are liable to crack. This would be serious as more water than the plant could afford to lose would evaporate through the cracks. Actually a layer of cork is formed somewhere in the external tissues with the result that no water can escape in this way. Consequently the tissues outside the cork die, forming bark. If the cork layer is superficial the bark is very thin, as in the beech and silver birch, but if it is deep and not continuous the bark is deeply furrowed, as in the elm and oak. Bark is formed on the older roots as well as on the stem. The cork of commerce is stripped from the cork oak, in which the layer is particularly thick. The cells which make up the cork layer lose their protoplasm, and their walls undergo considerable modification. The cells fit together very tightly and neither water nor air can penetrate this layer. The living cells inside the stem need air, and there are air spaces round all these cells which link up with air spaces along the medullary rays, which are vertical rows of cells running from the centre of the stem outwards. These rays connect up with little external ridges termed lenticels (Fig. 195) below which the cork cells do not fit together tightly and thus allow the passage of air into and out of the internal air spaces.

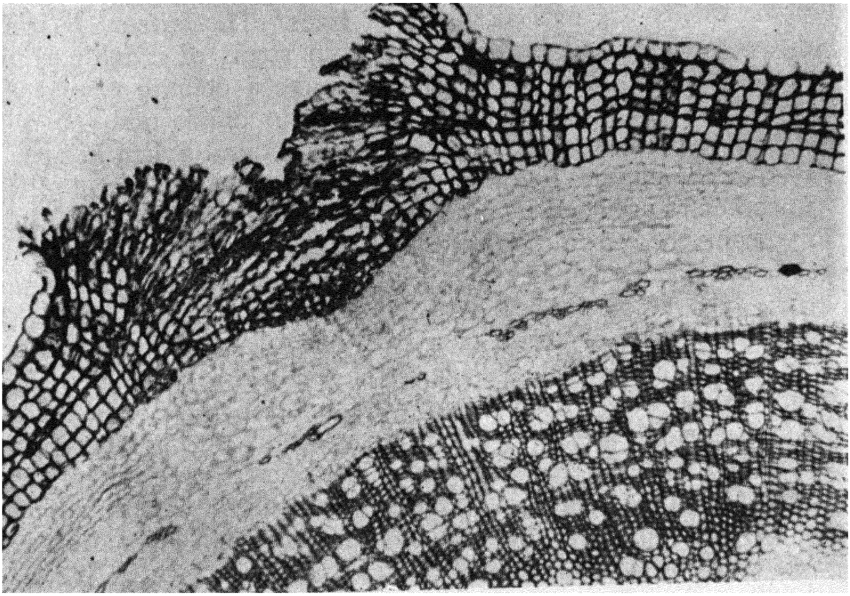


FIG. 195
Tranverse section of part of Elder stem showing a lenticel

Leaf-fall.—Most of our common trees, such as the oak, ash, sycamore and beech, lose their leaves in winter. They are termed deciduous trees to distinguish them from evergreens, such as the laurel, the holly and the pine, which lose their leaves at intervals throughout the year and remain green during the winter. While leaves of evergreens are very tough and leathery, the leaves of most deciduous trees change colour in the autumn. The green colour of the leaf is due to a substance called chlorophyll, which is actually a mixture of four different coloured substances. Two of these are green, but the other two, carotin and xanthophyll, are orange. As the green colour disappears in autumn, the orange pigments become more visible and there is thus a considerable change in the external colour of the leaf. Sometimes, as in the Virginian creeper, the leaves turn distinctly red. This is due to an increase in the coloured substances termed the anthocyanin pigments, which are also responsible for the red and blue colour of flowers. Any valuable material in the leaf is absorbed and passes along the conducting strands or veins in the leaf stalk into the twig. A layer of cork is

formed across the base of the leaf stalk. Food material cannot penetrate the cork and so the tissues of the leaf gradually die. Just outside the cork is found the absciss layer, the cells of which become rounded off and separated from one another (Fig. 196).

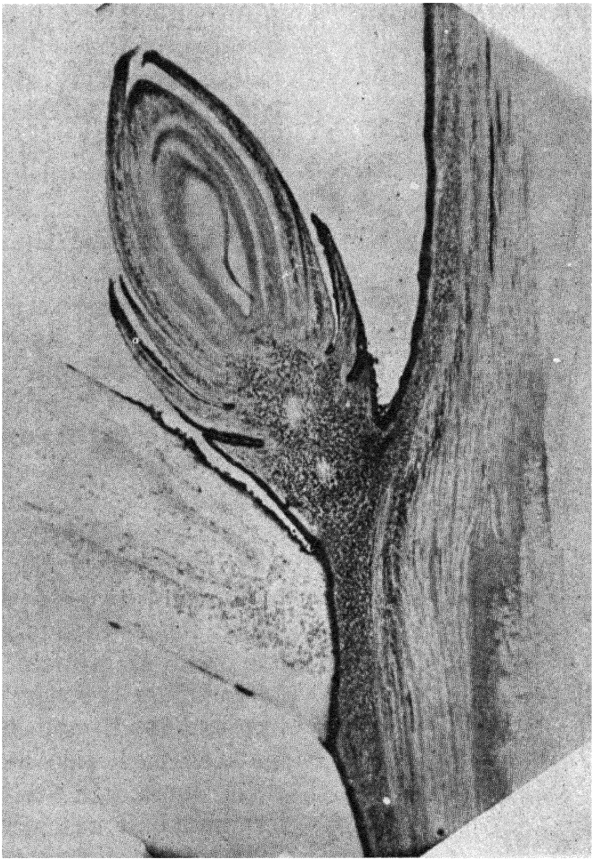


FIG. 196
Longitudinal section of part of Sycamore twig, showing the layer of cork formed across the leaf stalk in the autumn

This disintegration severs the leaf from the plant and it ultimately falls to the ground. The vein is the last part of the leaf to be cut off. The cork completely seals the scar so that no foreign bodies can enter.

Twigs.—The twig of a horse chestnut in its winter condition is

shown in Fig. 197. It bears a large brown terminal bud which is very sticky. If the bud is dissected, it is found that the outer bud scales give way to more recognizable foliage leaves surrounding the growing point in the centre. The gradual transition from bud scale to foliage leaf makes it clear that the bud scales cannot represent modified foliage leaves. They are in fact very much modified bases of the leaf stalk. The inner foliage leaves are also well protected by a covering of white hairs. The leaf scars are horseshoe shaped and very large. Each shows a ring of vein scars and has a bud in what corresponds to the axil of the leaf. The lenticels are very prominent. The twig began its existence as a terminal bud, and it is possible to calculate its age from the external features. At various points are crowded scars, at which the bud scales of a terminal bud were cut off when the main axis continued to grow. The region between any two of these girdle scars must therefore represent one year's growth. In some twigs there appears to be no terminal bud, and the axillary buds on each side have become quite large. In this case the terminal bud has grown into a flower, which has terminated its growth and left a "saddle scar."

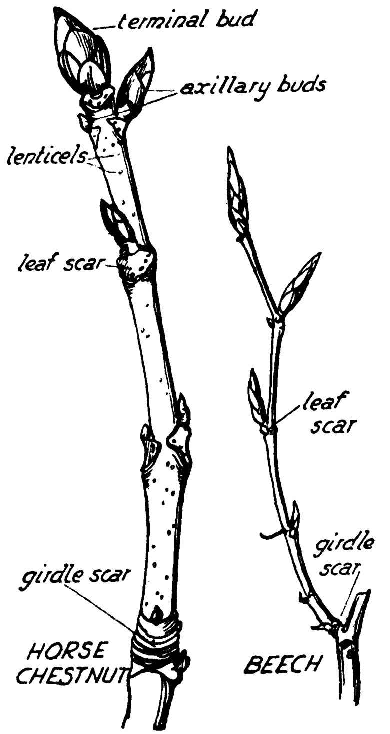


FIG. 197
Twigs of Horse Chestnut and Beech in the winter condition

The branching of a tree depends on the relative growth of the terminal and axillary buds. If the terminal bud is always large and always grows the effect will be that seen in a pine tree, where the central axis is very prominent and the shape of the tree that of an inverted cone. Though the terminal bud of the horse chestnut is so prominent, the shape of the tree is very different from that of the pine and it is clear that the branching of the main and of the lateral shoots must be different.

Twigs of other trees differ in minor points. The buds of the beech are long and pointed, and the bud scales in this case are arranged in pairs at the base of each of the inner foliage leaves. This indicates that they must be stipules, outgrowths of the leaf base which are protective in function. They occur in many plants, but do not usually persist when the leaf is mature. Beech twigs bear small dormant shoots which bear many girdle scars at very short intervals, showing that they have been growing for a number

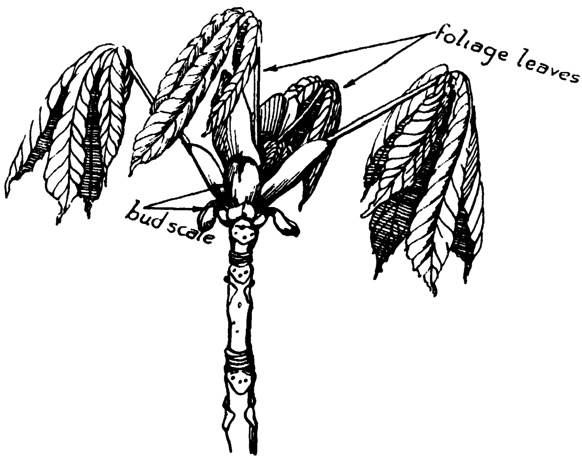


FIG. 198
Unfolding of Horse Chestnut bud in spring

of years. Ash twigs have very characteristic black buds and rather indistinct girdle scars. Oak twigs are more irregular and grow rather slowly.

By the time summer arrives the buds have grown, the main axis has extended, and the leaves have reached their full size. New buds will be visible in the axils of the leaves but as yet they are quite small. The shape of leaves varies considerably. A distinction may be drawn here between simple or entire leaves such as those of the beech, and compound or divided leaves, such as those of the horse chestnut and the ash.

CHAPTER XXVII

FOOD SUBSTANCES

ANY plant structure which is capable of survival over a period of time and of growing into a new plant must necessarily have a supply of food material to last until the plant is itself capable of feeding. Thus bulbs, corms, tubers and rhizomes all have a considerable quantity of reserve food stored in the modified stem or in the case of the bulb in the fleshy leaves. Seeds, too, have reserve materials stored either in the seed leaves (cotyledons) of the young plant or in another tissue inside the seed termed the endosperm. The same types of reserve food material are found in nearly all plants, and it is possible to detect them by means of chemical tests. Reserve foods are nearly always stored in a very compact, solid form, usually inside certain cells in the structure concerned. Thus, in the wheat grain, a longitudinal section of which is shown in Fig. 199, practically all the cells of the endosperm contain a large number of grains of starch, while the cells immediately under the seed coat contain solid particles of a substance termed glutin (Fig. 200). Thus, flour, which is manufactured by crushing wheat grains, consists chiefly of starch grains together with a little glutin. As may be seen in the figure, most of the grain consists of endosperm,

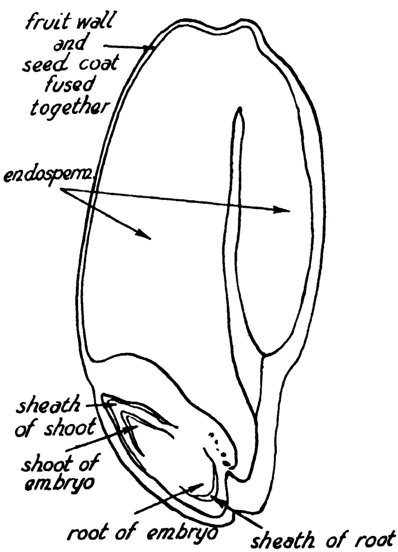


FIG. 199
Longitudinal section of a wheat grain

and the embryo is connected with it by the part of the single cotyledon termed the scutellum. The other parts of the cotyledon protect the young root and the young shoot.

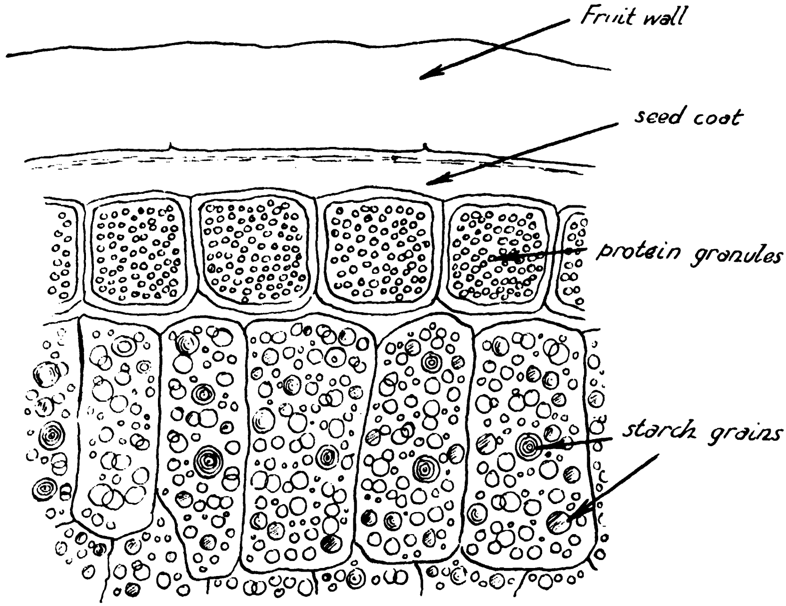


FIG. 200

Section of outer layer of wheat grain in the region of the endosperm

Stored Food in Plants.—Starch is the commonest reserve product of all, and is found not only in the special organs previously mentioned but in many other parts of the plant, notably the leaves. Wheȧt and other cereals, notably rice, constitute a very important source of commercial starch. Starch grains are found abundantly in most seeds, and also in corms and tubers, which also form a source of the commercial product. The individual grains have a very characteristic structure, consisting of concentric layers. Starch can always be detected very readily, as it has a very characteristic reaction with iodine. The latter is a solid, but it is used in solution, either in alcohol, which is the ordinary tincture of iodine, or in an aqueous solution of potassium iodide. If the cut surface of a wheat grain or a potato tuber is smeared with either solution of iodine, a blue-black coloration will be the result, indicating quite clearly the presence of starch. The same test may also be carried out on

a slide under the microscope. In this case, a little diluted iodine solution is added to a thin section of the seed or tuber, cut with a razor, and it is possible to see the individual starch grains becoming blue.

Many different kinds of sugar are stored in plants. The sugar extracted from the sugar cane is called cane sugar. A simple kind, grape sugar or glucose, is found in many types of fruit including grapes and also in other parts of plants. Most sugars can be detected chemically by means of Fehling's solution. If small pieces of the fleshy scale leaves of an onion bulb are boiled with this solution a reddish-brown precipitate is formed. Cane sugar cannot be detected by means of this test. Sugar is soluble in water and is stored in solution and thus it is never likely to be found in quantity in such dry structures as seeds.

Some seeds contain little if any starch, the food reserves being of quite a different nature. Thus, if a section of a castor oil seed is examined under the microscope, many tiny droplets of oil will be seen. Oil gives a black colour when treated with a substance known as osmic acid, and if the latter is applied to the section, it will turn black, and so will the tiny droplets which are floating round it. Another, if crude, test for oil in a seed, is to crush it, using a pestle and mortar, and to wipe the mortar with a piece of good writing-paper. If much oil has been liberated by the crushing there will be a characteristic greasy mark on the paper.

The castor-oil seed also contains granules of another class of foodstuff known as protein. Proteins can be detected very simply by the use of Millon's reagent, which is prepared by dissolving mercury in nitric acid. When the reagent is added to any protein, such as the white of egg, a white compound is formed which turns to a characteristic brick-red on heating. This test can be applied either by heating small pieces of the seed with the reagent in a test-tube, or by heating a section of the seed in a drop of the reagent on a microscope slide over a small flame.

Carbohydrates, Fats and Proteins.—These names are very familiar to those who read modern advertisements. They are three classes of chemical foodstuffs which, for a variety of reasons, are essential to all living organisms. The primary reason is that the protoplasm itself consists very largely of these compounds, dissolved or suspended in water. Many of these substances are used up in the normal activities of life and must be replaced. Further, as growth involves the formation of new protoplasm,

there can be no growth unless there is a supply of the necessary raw materials.

Starch, cellulose and sugar are examples of carbohydrates. The latter name is given to this group because the molecule contains, in addition to carbon, atoms of hydrogen and oxygen united in the same proportions as in water, namely, two of hydrogen to one of oxygen. Thus the molecule of glucose consists of six atoms of carbon, twelve atoms of hydrogen and six atoms of oxygen. Its formula is therefore $C_6H_{12}O_6$. Cane sugar is rather more complicated, and has a larger molecule with the formula $C_{12}H_{22}O_{11}$. Starch is much more complicated and has an enormous molecule, consisting of thousands of units, each composed of six atoms of carbon, ten atoms of hydrogen and five atoms of oxygen. Cellulose is even more complicated than starch. Plant material necessarily contains a great deal of cellulose, as the cell walls of living cells consist of this substance. Many materials prepared from a vegetable source, such as paper and cotton, consist very largely of cellulose, as also does silk, which is formed by silk worms from the cellulose in the mulberry leaves on which they feed.

Fats and oils are very similar compounds, oils being "fatty" compounds which are liquid at ordinary temperatures. Many oils, such as linseed oil, castor oil and olive oil, are derived from plants; cod-liver oil is derived from an animal. Suet is an example of animal fat, and there is little need to point out that fat is a constituent of beef, pork and lamb. Chemically, fats are composed of the same three elements as the carbohydrates, but in very different and varying proportions. An important point is that they contain relatively little oxygen.

Proteins are much more complicated than either carbohydrates or fats. In addition to carbon, hydrogen and oxygen, they contain nitrogen and usually sulphur and phosphorus. Protein molecules are very large indeed and often contain thousands of atoms. Common examples of proteins are white of egg (albumin), yolk of egg, lean meat, and glutin in wheat grains and flour. When proteins are stored in plants, they occur in the form of grains, which often, though not always, are contained in a superficial layer of cells immediately below the seed coat, as in the wheat grain, and immediately below the skin of the potato tuber. Sometimes they are generally distributed throughout the cotyledons, as in the pea and lupin seeds, or throughout the endosperm, as in the castor-oil seed.

The Conversion of Food Materials into Simple Substances.—When a little cane sugar solution is heated with dilute hydrochloric acid and sodium hydroxide added to neutralize the excess acid, the product gives a red precipitate when heated with Fehling's solution. Cane sugar itself does not react with Fehling's solution, and it must therefore have been changed into a substance which will react with this solution. In fact, glucose and another simple sugar, fruit sugar or fructose, are formed. Thus:

$$\text{cane sugar} \longrightarrow \text{glucose and fructose.}$$

In exactly the same way, a little starch suspended in water will, after boiling with rather stronger hydrochloric acid than that used above, give the same result. In this case, malt sugar and glucose are formed in succession:

$$\text{starch} \longrightarrow \text{malt sugar} \longrightarrow \text{glucose.}$$

The reactions are due to the splitting of the complicated carbohydrates by the addition of the elements of water. This type of change is termed hydrolysis.

Fats and proteins may be hydrolysed in a similar way. Fats are usually hydrolysed by boiling them with an alkali, and, in this case, glycerine and acids, appropriately termed fatty acids, are formed. This process is utilized on a large scale for the manufacture of soap (p. 173), as the excess alkali combines with the fatty acids to form soap. Glycerine is, of course, also a very important product of this process. Thus:

$$\begin{array}{c}\text{fats}\\ \text{or oils}\end{array} \longrightarrow \text{glycerine} + \text{fatty acids.}$$

When proteins are hydrolysed, compounds termed amino-acids are formed. They are called amino-acids because each contains one or more of the unit consisting of one nitrogen and two hydrogen atoms (NH_2), which is termed the amino group. Thus:

$$\text{proteins} \longrightarrow \text{amino-acids.}$$

Enzymes.—The hydrolysis of compounds happens very frequently in the living organism, though it does not, of course, involve boiling with an acid or alkali. Food material is stored in both plants and animals in a complicated and usually in a solid insoluble form. When it is needed by the organism, it is converted once again into simpler soluble compounds. The starch which accu-

mulates in the wheat grain or the potato tuber is formed from sugar, in this case glucose, which is brought to it from the parent plant. The germinating seed or tuber needs soluble food which has to be conducted to the tips of the young root and the young shoot. Thus starch, when needed, is converted once again into soluble sugar.

It will be remembered that, in the preparation of oxygen, a substance was used which remained unchanged chemically at the end of the reaction, but which enormously quickened up the rate of oxygen production. The manganese dioxide was, in this reaction, acting as a catalyst (p. 54). In much the same way, hydrolysis in living organisms is brought about by compounds which are termed enzymes. Thus, the starch-to-sugar change mentioned above is, in plants, greatly speeded up by the enzyme diastase. In the organism these changes happen very much more quickly than corresponding changes carried out in a laboratory. As with most catalysts, only a small quantity of the enzyme is necessary. It is now known that this enzyme, diastase, also speeds up the conversion of sugar into starch suitable for storage. These changes may be represented thus:

$$\text{starch} \underset{\text{diastase.}}{\rightleftarrows} \text{sugar}$$

Diastase will only act as a catalyst in this particular reaction.

In much the same way, fats are changed into glycerine and fatty acids, and back again into fats, by another enzyme, lipase, which will not catalyse any other reaction. Proteins are converted by stages into amino-acids and back again by other enzymes which will not affect fats or carbohydrates. Enzymes differ, in some respects, from inorganic catalysts in that they are only formed by living protoplasm and that they are put out of action when they are boiled or even, in most cases, if they are heated to 50° C.

Experimental Work on Enzymes.—The catalytic activity of lipase may readily be shown in the following experiment. A castor-oil seed is ground up in a mortar and is put into a test-tube which is half filled with water. A little blue litmus is added, the tube is plugged with cotton-wool, and the mixture is left for several days. A similar experiment is set up with the one difference that the castor-oil seed extract is boiled before the litmus is added. Lipase is present in the castor-oil seed and in the course of a few days fatty acids are set free and the blue litmus turns pink. In

the second case the lipase is destroyed by boiling and the litmus will not therefore change colour.

A similar experiment may be performed in the case of diastase, which occurs in plants, in, among other places, green leaves. An extract of cabbage leaves is made by crushing and extracting with water, a little starch " solution " is added, the tube plugged with cotton-wool and left for several days. A similar experiment, using boiled cabbage extract, is also set up in the same way. At the end of several days it should be possible to demonstrate the presence of sugar in the first experiment by means of Fehling's solution.

CHAPTER XXVIII

THE DIET OF ANIMALS

PROTOPLASM itself consists of particles or droplets of complex carbohydrates, fats and proteins, suspended in an aqueous solution of sugars, amino-acids and various other substances. The chemical composition of the protoplasm of plants and animals is practically identical. Although much is known of the chemical nature of protoplasm, it is not possible to build it up in the laboratory. When an organism grows, new protoplasm is formed and the raw materials for its formation must come from the food. Carbohydrates, fats and proteins are, therefore, required for this purpose, and, partly for this reason, our food must consist very largely of these compounds.

In Chapter XXIV it is explained that fuel is a source of chemical energy, which, when liberated, is converted into forms of energy, such as heat, light, or electrical energy, which is capable of doing work. The fuel of organisms consists of their food, and the energy which they need to carry on their activities is derived from this source. Thus, carbohydrates, fats and proteins are also utilized by organisms for the purpose of energy production. As in the case of the petrol or steam engine, oxygen is necessary for the combustion of the food, and simpler waste substances are formed as a result of combustion.

Thus, food is utilized for the formation of new protoplasm and also for energy production. There are, therefore, many chemical reactions going on in protoplasm, for, in addition to the building up and breaking down processes previously mentioned, the food is often stored up in an organ, and broken down into simpler soluble substances when required. The word metabolism is used to denote the sum total of the chemical processes going on in the body or in any part of the body. Thus, it may be said that our own metabolism is essentially similar to that of a frog or an earthworm.

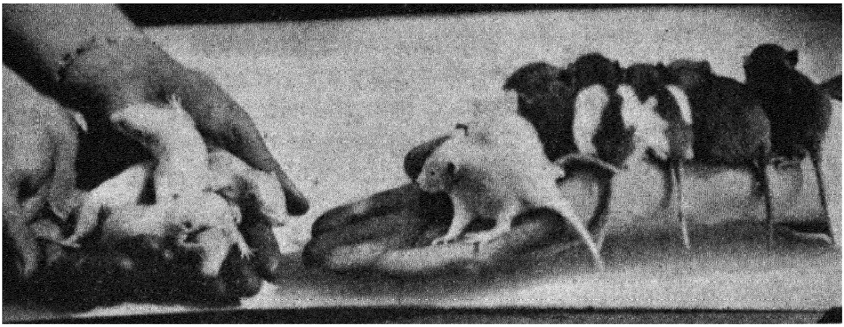
Water and Salts.—In addition to carbohydrates, fats and

proteins, other types of substances must be included in the food of organisms. For a variety of reasons, organisms must be adequately supplied with water. Protoplasm consists very largely of water; blood and sap are very largely water too. This is presumably chiefly due to the importance of water as a solvent. Water is concerned in many animal and plant mechanisms, notably in the maintenance of rigidity in young plants. It is a well-known fact that lack of water is much more rapidly fatal than lack of food.

Inorganic salts, too, play a most important part in many processes, as they provide various necessary elements which are not present in other foodstuffs. Thus, the red substance in our blood is a compound of iron, derived from salts of this metal present in foods such as green vegetables and meat. There must also be a supply of calcium salts, which form part of the raw material for our bones and teeth.

Vitamins.—During the last thirty years, it has been shown that certain diseases, which had been well known for centuries, are due to the absence of small quantities of certain definite compounds in the food. For instance, it had been known since the time of Captain Cook that scurvy, a disease very prevalent on sailing-ships, could be prevented by an adequate ration of lemon-juice each day. Those suffering from the disease could be cured quite simply in this way, provided the disease had not gone too far. The actual substance effecting the cure has now been isolated from the juices of raw fruits and vegetables, and it belongs to the class of substances known as vitamins, of which many are now known. The example mentioned above is known as vitamin C, and it is found in many raw fruits and vegetables, in particular in spinach and cabbage. Vitamin B has now been shown to consist of at least two vitamins, called B_1 and B_2. The absence of the former produces a disease known as beri-beri, which finally causes paralysis. This disease is very prevalent among rice-eating peoples in the East, as the vitamin is in the husk of the rice which is usually removed before the rice is eaten. Vitamin B_1 is present in nuts, wheat, wholemeal flour, liver, and, to a certain extent, in fruit and vegetables. The effect of the absence of B_1 from the diet of young rats is shown in Figs. 201, 202. B_2 comprises several substances, the absence of one of which causes pellagra, involving digestive and skin troubles among others. It is common in parts of the world, such as parts of Central Europe and the southern part of the U.S.A., where food is scarce and contains barely any

meat, milk or cheese, all of which contain the vitamin. Yeast and yeast extracts are very rich in both B_1 and B_2.

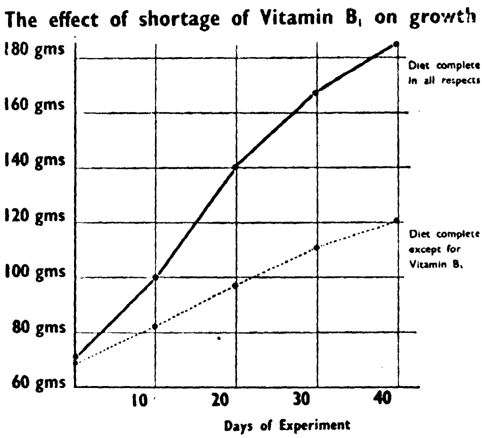


By courtesy of Vitamins Ltd.

FIG. 201

Young rats showing effect of shortage of Vitamin B_1 on growth (*see Fig.* 202)

Vitamins A and D can be considered together in that they are both found in foods containing fat such as cod-liver oil, butter,



By courtesy of Vitamins Ltd.

FIG. 202

Graph showing effect of shortage of Vitamin B_1 on growth (*see Fig.* 201)

and similar foods, though A is also found in vegetables and fruit The symptoms of vitamin A deficiency are inflammation of the transparent layer in front of the eye, involving a form of " night

blindness" which renders vision in the twilight difficult. Ultimately, total blindness may be the result. The vitamin has also a pronounced effect on growth. Vitamin A is formed from a substance called carotin, which is the yellow colouring matter in the tap root of the carrot, and which is a constituent of the chlorophyll in all green plants. It is not necessary for vitamin A itself to enter the body as carotin is converted into the vitamin in the liver and other organs. A similar change happens in the case of vitamin D, which is formed by the action of ultra-violet rays on a substance dissolved in the fat just under the skin. Consequently, vitamin D can either be taken in with food, or can be formed inside our bodies by the action of ultra-violet rays on the skin. The disease caused by vitamin D deficiency is rickets, which is very common indeed in cases of malnutrition in all countries. Rickets is due to the failure of the bones to harden, the bones becoming misshapen and the joints failing to work efficiently. It may, of course, be due to shortage of lime salts in the food, without which the bones cannot harden. Vitamin D has also a very pronounced effect on the well-being of the teeth. Animals deprived of vitamin E will not produce any young, though apparently healthy in every way. The vitamin is present in small quantities in fresh foods.

The absence of any one vitamin usually involves a general lowering of resistance to diseases as well as its own particular effects. In general, only a small quantity of a vitamin is necessary, and the substance is usually found in a wide variety of fresh foods. A great deal of research work is being done on this subject, and every year more becomes known about vitamins.

Energy Content of Food.—The energy content or calorific value of food substances is very high. Thus 1 oz. of carbohydrate or protein will produce 116 Calories (p. 81), while 1 oz. of fat will produce 263 Calories if completely oxidized (combusted). It is possible by various means to estimate how many Calories per day are needed by the average man. When we are asleep, various activities are still going on, such as the contraction of the heart and of the muscles used in breathing, and energy equivalent to 70 Calories is used up every hour. When we are awake more muscles come into action and something like 90 Calories per hour are required. If any muscular work is to be done, the energy requirement becomes much greater, and something like 1,000 Calories must be added for eight hours of ordinary muscular work. The total for twenty-four hours for an average adult working man

is thus about 3,000 Calories. For a really vigorous worker, such as a navvy, it might be as much as 5,000. An average adult woman would require about 2,500, a child of twelve about 2,300. Not all the food can be digested completely and so about 10 per cent. ought to be added to the above figures to allow for this factor.

Planning a Diet.—The ratio of carbon to nitrogen should remain roughly constant and it is found that supplying the Calories in a ratio of two-thirds from carbohydrates to one-sixth from fat and one-sixth from protein yields the best results. Protein supplies both carbon and nitrogen, but there is relatively little carbon, and about six pounds of lean meat would have to be eaten every day to obtain an adequate supply of carbon from this source alone. This obviously involves far too great a supply of nitrogen. Bread consists mainly of starch, with a little protein: a diet of bread alone would involve eating about four pounds every day to obtain sufficient nitrogen. In our own case, proteins derived from animals, including such food materials as fish, cheese, eggs and lean meat, are particularly valuable for growth since the amino-acids produced from them are more readily available for building up new protoplasm than are those derived from plants.

From the facts given above, and from the information given in Fig. 203, it is possible to build up a satisfactory diet for the average man requiring 3,300 Calories daily. Since two-thirds of these must be from carbohydrates, these substances must be responsible for 2,200 Calories—produced by $\frac{2200}{116}$, i.e. 19 oz. Similarly, there ought to be $\frac{550}{116}$, i.e. $4\frac{3}{4}$ oz. of protein and $\frac{550}{263}$, i.e. $2\frac{1}{8}$ oz. of fat. It is now possible to begin to plan a day's diet, based on scientific principles. Thus, the amount of protein eaten during the day should not be less than $4\frac{3}{4}$ oz. and some of it should be derived from animal sources. The quantity of carbohydrates, such as those in bread, rice, potatoes, fruit and vegetables, should not be less than 19 oz., and the fat, such as butter, meat fat, lard, cod-liver oil, not less than $2\frac{1}{8}$ oz. The quantities actually eaten will probably be greater than those mentioned, but some of the food may not be worth very much from the point of view of nutrition.

Many points have, therefore, to be taken into consideration when planning a diet for any animal. The proportion of carbohydrates, proteins, fats and salts must be roughly correct. The calorific value and vitamin content must be adequate. It is also

highly important that the food should be made as attractive and palatable as possible and that there should be considerable variety.

FIG. 203

PERCENTAGE COMPOSITION, CALORIFIC VALUE AND VITAMIN CONTENT OF SELECTED FOODSTUFFS

Food.	Protein.	Fat.	Carbohydrate.	Salts.	Water.	Fibre.	Calories per oz.	Vitamins.
Leg of mutton .	22	7	—	1	70	—	43	A B_2
Sheep's liver .	21	3	4	1	71	—	36	A B_1 B_2 C D
Ham (slice) . .	12·5	47·5	—	5	35	—	138	B_2
Mackerel (flesh)	19	10	—	2	69	—	50	D
Cow's milk (fresh)	3·5	4	4·5	1	87	—	19	A B_1 B_2 C D
Cheese (Stilton).	27	41	4	3	25	—	146	A D
Hen's egg (without shell) . .	12·5	10	2	1·5	74	—	46	A B_1 B_2 D
White flour (wheat) . .	10	1	75	1	11	2	104	—
Wholemeal flour (wheat) . .	12	1·5	72	1	12	·5	102	A B_1 B_2
Green peas (dried)	20	1	57	3	12	7	92	B_1 B_2
Orange (edible part) . . .	1·5	—	7·5	1	87	3	11	A B_1 B_2 C
Cabbage . . .	2	—	2·5	2	91·5	2	7	A B_1 B_2 C
Brazil nut . .	14	68	8	3	4	3	210	B_1 B_2

[Based on information from *Food Values at a Glance*, V. G. Plimmer.]

CHAPTER XXIX

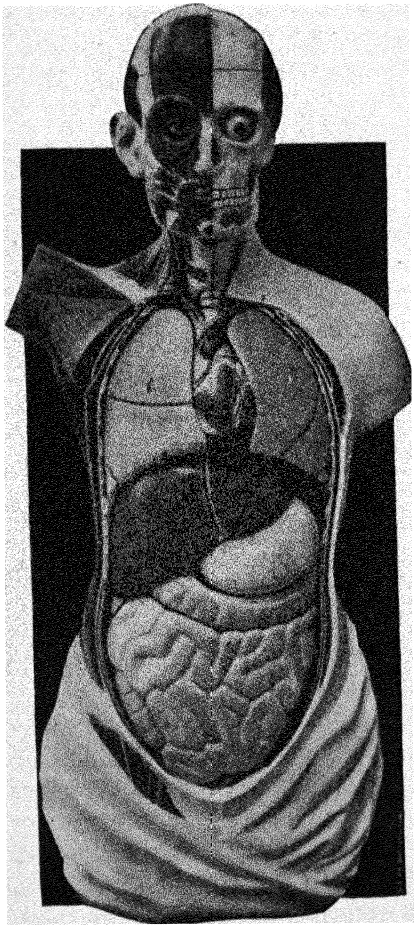
THE DIGESTIVE SYSTEM

ANIMAL cells are usually smaller than those found in plants, and their boundaries are more difficult to define, since they have no cell wall. The cells are differentiated to perform various functions, such as support, contraction, conduction of impulses and secretion of juices. The tissues, each consisting of the same type of cell, are usually much more distinct from one another than are plant tissues. Examples are bone and cartilage (Fig. 236), muscular tissue (Fig. 246), nervous tissue (Fig. 240) and glandular tissue (Fig. 244). These different types of cell will be described in the chapters dealing with the various functions of the animal body. It is merely necessary here to examine a microscope slide of glandular tissue, such as a section of the glands which produce saliva, in which the cells are usually clearly visible. These cells are usually little modified structurally, but have a relatively large nucleus, and usually contain particles of a substance related to that which the gland secretes. In animals several types of tissue are usually grouped together to form an organ, and several organs are associated to form a system. Thus, muscular, glandular, lining and various other tissues are found in the organ known as the intestine or alimentary canal, but the digestive system includes several other structures, such as the liver, in addition to the canal itself.

Vertebrate Animals.—The most complicated animals are those which possess a spine or backbone. Animals such as worms and insects, which do not possess an internal skeleton, are termed invertebrate. Vertebrate animals include fish, frogs, lizards and snakes, birds and mammals. The latter, which include cats, dogs, rabbits, elephants, whales, monkeys and man himself, are the most complicated of all. Their most obvious characteristics are that they are covered with hair and that they suckle their young.

The Internal Anatomy of a Mammal.—The internal organs of a vertebrate animal can best be observed if the animal is cut

open from the under or ventral side. When the body wall of a rabbit is cut through, the organs themselves come into view. They lie in a cavity termed the body cavity, or coelom, suspended from the upper or dorsal side by mesenteries. Each mesentery is a double thickness of the peritoneum, which forms the internal lining of the body cavity. Not only do these mesenteries suspend the organs but they also carry the blood vessels and nerves which pass into them.



By courtesy of Messrs. Baird & Tatlock

FIG. 204

Contents of human body cavity. In the thorax are the heart and lungs, in the abdomen the liver, stomach, small intestine and large intestine

The body cavity of a mammal is divided into two by a thin sheet of muscle termed the diaphragm. The chest or thorax contains the heart, the lungs, the gullet and important blood vessels. The lower cavity or abdomen contains many important organs, which are shown in Fig. 204. The liver, which is large and consists of several lobes, lies immediately below the diaphragm. The remainder of the cavity is largely filled by various parts of the alimentary canal. The kidneys lie just above the peritoneum on the dorsal side of the cavity.

Digestion.—The food of an animal usually enters the body in a compact insoluble form. Before it can be used, either for the formation of new protoplasm or for energy production, it must be converted into simpler soluble compounds which can pass into solution in the blood stream. This process is known as

digestion, and it is brought about by enzymes in a special tube termed the alimentary canal or more simply the intestine or gut.

In the simplest animals there is no intestine or blood system, and food is digested anywhere in the body. The usual form of intestine is a tube with muscular walls, together with various associated structures, such as glands which produce digestive juices. The digested food passes into the blood vessels which run in the wall of one special region of the intestine, and is distributed to other regions of the body in this way. Thus the greater the internal

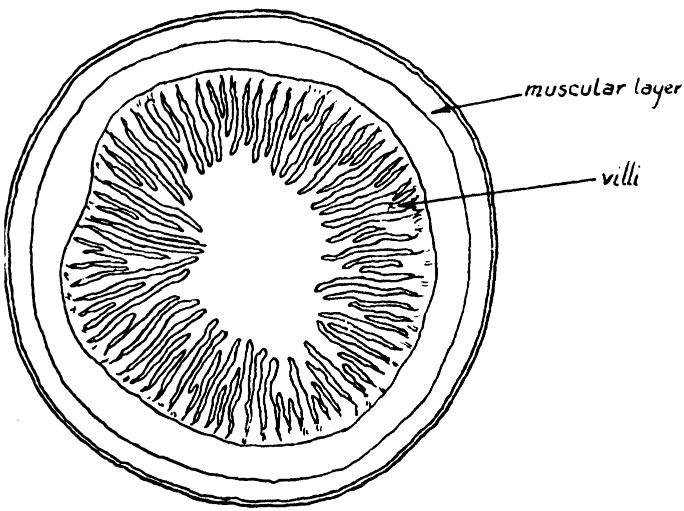


FIG. 205
Tranverse section of small intestine of dog

surface area of this part of the intestine the more food will be absorbed. A good example of an animal with a well-developed but simple intestine is the earthworm. Here the intestine is a straight tube, but even so there is a device which increases the internal absorptive area. This device consists simply of a longitudinal ridge along the upper part of the tube. In the higher animals, the area capable of absorbing food is very large. In mammals, for example, the region known as the small intestine is very long, and in man is some twenty-four feet in length. The internal surface is covered by very numerous small projections called villi, which make the effective area even greater (Fig. 205).

The Jaws and Teeth.—The digestive process begins in the

mouth, for here the food is usually chewed into very small pieces in order to present a large surface to the digestive juices with which it will come into contact.

The upper jaw is fused to the under side of the cranium and nose, leaving the nasal passages between them. The lower jaw consists of a single bone, known as the mandible, on each side, which fits into a socket just in front of the ear, and is moved up and down by means of muscles. The teeth of mammals, unlike those of other vertebrates, are fixed into sockets in the jaw and held in position by means of a special type of bone termed cement. The part of the tooth embedded in the jaw is termed the root, that above the gum, the crown (Fig. 206). The larger teeth have divided roots and a crown consisting of several projections termed cusps. The bulk of a tooth consists of a bone-like tissue, known as dentine, the crown being covered by a layer of very hard enamel, which is another type of bone. The tooth is supplied by blood vessels and nerves which run into the central or pulp cavity through the roots.

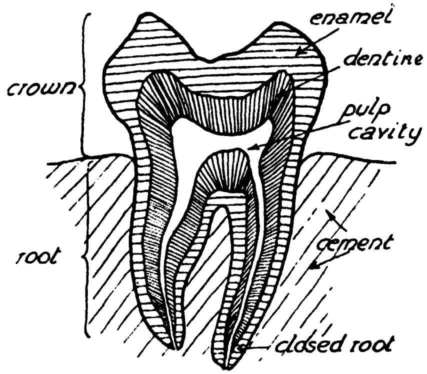


FIG. 206

Longitudinal section through human molar tooth

Each jaw has teeth of four different kinds embedded in it. Those in front are called the incisors, and are simple teeth, usually used for gripping the prey or food. Immediately opposite the junction of the bone bearing the incisors with that behind it is a large tooth called the canine, or dog tooth. The first set of teeth in mammals is termed the milk set; these drop out sooner or later and are replaced by a second or permanent set. Of the teeth behind the canines, some, the premolars, are represented in the milk set, but those at the back, the molars, are not. The canines, when large, are usually weapons of offence, but the premolars and molars are used for chewing or grinding. Carnivorous animals, such as the dog, usually have a special pair of teeth, termed the carnassials, for cutting through bones and flesh. In the dog this pair consists of the last premolar in the upper jaw and the first molar in the

lower. The number of teeth of different kinds in any particular mammal can be expressed by means of a dental formula, which refers to the number of teeth in one side of each jaw. Thus, in the dog the formula is:

$$i\frac{3}{3}\ c\frac{1}{1}\ p\frac{4}{4}\ m\frac{2}{3} = 42$$

or, more simply $\dfrac{3143}{3143} = 42$.

Types of Tooth found in other Vertebrates.—Teeth vary enormously in size and shape, also in the pattern of their cutting ridges. This variation is very largely due to the varying nature of the food of different animals. Carnivorous animals such as the dog (Fig. 207) use their teeth to grasp and kill their prey as well as to cut through flesh and bone. The teeth of these animals differ

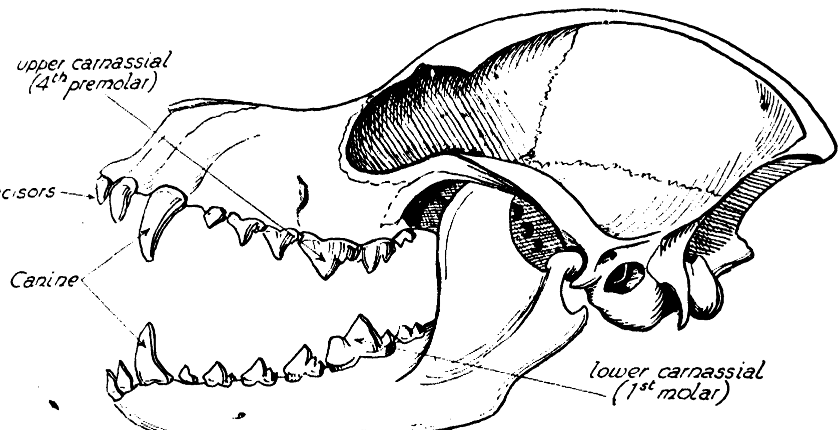


FIG. 207
Skull of dog

in many respects from those of herbivorous animals, which live on food containing much cellulose, a very difficult substance to chew into sufficiently small pieces for digestive purposes. A totally different type of tooth is thus required, and, in herbivorous animals, the premolars and molars are usually very flat with raised enamel ridges which form a distinctive pattern. In the sheep (Fig. 208), these ridges take the form of crescents, but in the rabbit and in the Indian elephant, they form parallel ridges at right angles to the

axis of the jaw. The sheep has no front teeth in the upper jaw, but grasps the grass largely by means of its tongue. The lower jaw does not fit tightly into the skull and is capable of rotary movement which is very effective in drawing pieces of grass across the crescentric ridges. Sheep and other related animals such as the cow and deer after swallowing the food indulge in the process known as "chewing the cud" (p. 274). Rodents, such as the rabbit, have very large incisors, which are adapted for gnawing.

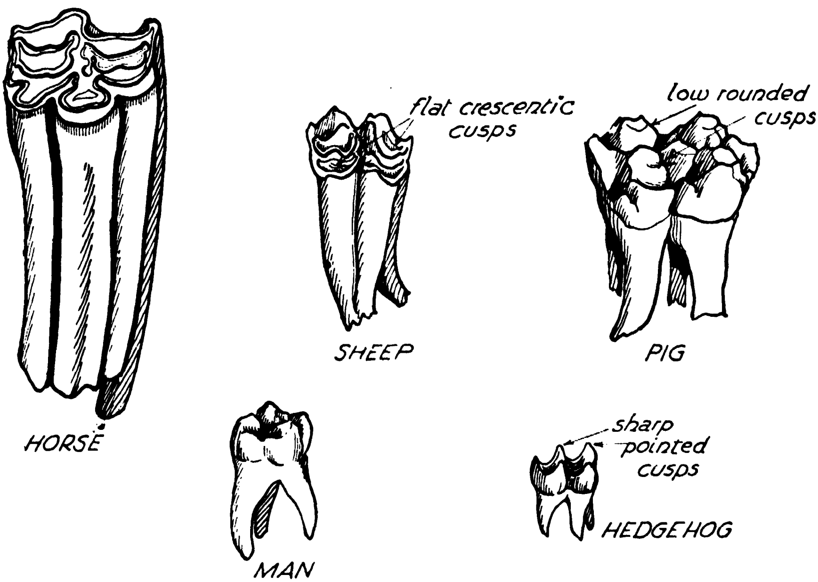


FIG. 208

Molar teeth of various animals

These teeth continue to grow throughout the life of the animal, and as fast as they are worn away at one end they grow at the other.

Many mammals feed on both animal and vegetable material. The molars in such cases are intermediate in character between those of carnivorous and herbivorous animals. Our own molars are of this type, as also are those of the pig. The dental formula of man is $\frac{2123}{2123} = 32$. In birds there are no teeth, but the jaws are prolonged into a horny beak, which also varies in shape and size according to the diet of the bird concerned. Thus, the beak of

a hawk is quite different from that of a grain-eating bird such as a pigeon. In fish, frogs and reptiles the teeth are often very numerous, and merely fused to the jaw, not embedded in sockets. These teeth are not used for chewing but for capturing and retaining their prey.

Digestive Processes.—The actual process of digestion is much the same in all mammals. Indeed, it is much the same throughout the animal kingdom, though the degree of elaboration of the intestine naturally varies greatly. The following account is a description of the process in the rabbit, though reference will sometimes be made to man. The rabbit has four pairs of salivary glands opening into the mouth. We have only three pairs, the most important of which lie just below the cheek on each side. It is possible to follow the flow of saliva along the ducts into the mouth when sucking. In cases of mumps these glands become much enlarged. When there is food in the mouth the saliva is poured on to it from the glands, but it only begins to act on one constituent, namely any boiled starch present. This is converted by the enzyme, ptyalin, into a sugar, but this change is not completed until the food finds its way into the stomach a little later. The saliva is alkaline, an important point since the ptyalin can only work in an alkaline medium.

One of the most important functions of the saliva is to act as a lubricant in swallowing. When the food passes over the entrance to the wind-pipe, a valve called the epiglottis is pushed down over it by the tongue, so preventing food from "going the wrong way" (Fig. 209). This means, of course, that breathing is stopped for a very short time in the act of swallowing. The food is squeezed along the gullet, as in other parts of the canal, by a wave of contraction of the muscles in its wall. This type of muscular action is called peristalsis. The food thus enters the stomach (Fig. 210), which, in addition to its function of storage, also has in its walls glands which produce a juice containing enzymes. This gastric juice is acid, owing to the presence of a small quantity of hydrochloric acid and this property puts an end to the activities of the starch enzyme as soon as it permeates throughout the food. The most important enzyme in the gastric juice is called pepsin, and its function is to turn proteins into soluble substances called peptones, which are still, however, fairly complicated in structure. In the young mammal the gastric juice also contains an enzyme (rennin) which converts a substance in milk into an insoluble sub-

stance (casein), in order that the passage of the milk through the intestine can be slowed down so as to give the other enzymes a chance to digest the substances in it.

[The stomach of animals which " chew the cud " is very different in appearance from that of other mammals. It consists of four compartments, of which the last corresponds to the true stomach, the others being enlargements of part of the gullet. The food is

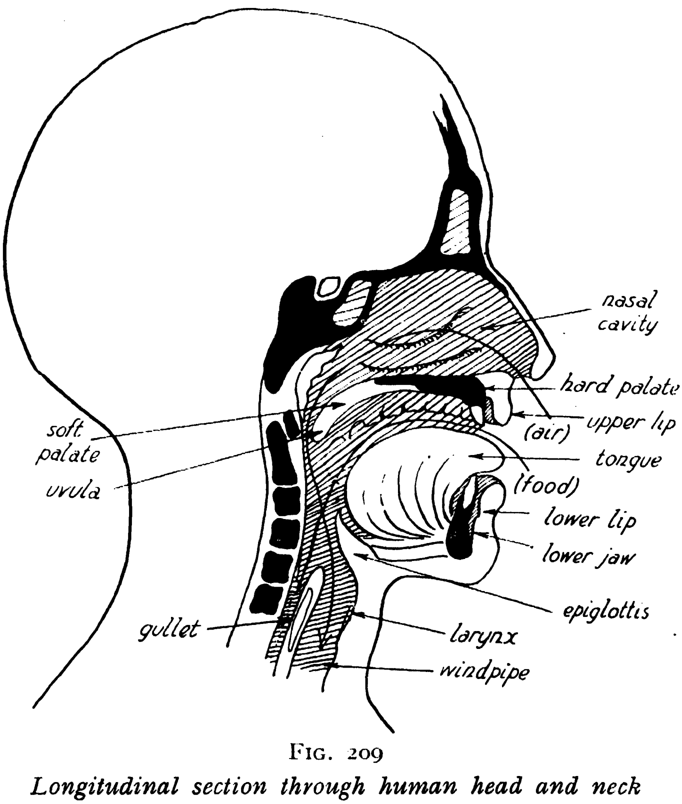


FIG. 209

Longitudinal section through human head and neck

first chewed for a short time, then passed down the gullet into the rumen or " paunch " in which it is stored. The food later passes up the gullet and into the mouth again where it is chewed into very small pieces, which pass down the gullet, through a kind of filter and into the true stomach. The whole process is probably connected with the fact that wild herbivores often have to emerge into the open to feed, and it is a great advantage to be able to " bolt " food and rapidly retreat into a place of safety.]

The food passes out of the stomach at intervals into the duodenum through a circular muscle, which relaxes and acts as a valve. The duodenum is the first part of the small intestine and is so called because it is twelve inches long in man. The special function of the duodenum is that it receives the products of the activity of the liver and of the pancreas or sweetbread, which is a large gland between the stomach and the duodenum (Fig. 210). The liver is an extremely

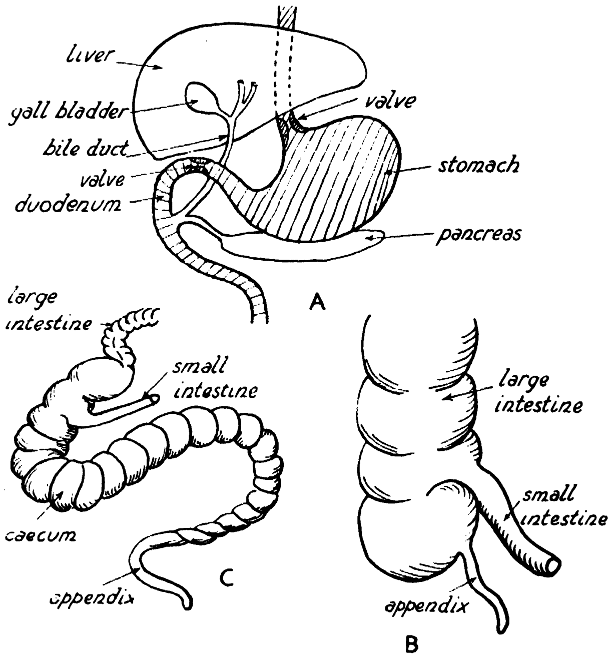


FIG. 210

A. Human liver, pancreas, stomach and duodenum ; B. Human cæcum and appendix ; C. Rabbit cæcum and appendix

important organ, which stores large quantities of glycogen, a carbohydrate resembling starch, and also controls the storage of fat in various parts of the body. Waste products, such as urea, are also formed in the liver. The secretion of the liver, which is called bile, is stored up in the gall bladder and is discharged into the duodenum. The bile does not contain any enzymes, but it is alkaline and it contains substances which cause the large fat droplets in the food to break up into smaller droplets, an important point since the fat enzyme, lipase, which is present in the pancreatic juice,

can act more readily on smaller than on larger droplets. The secretion of the pancreas, which is also passed into the duodenum, contains in addition a protein-enzyme and a starch-enzyme. [The pancreas also produces a substance known as insulin, which is liberated into the blood-stream. This substance is essential for the storage and combustion of glucose. If, for any reason, the pancreas fails to produce an adequate supply of insulin, the body can make no use of sugar, which escapes in the urine. This condition is known as sugar diabetes and can be rectified if the patient is supplied with a daily dose of insulin.] The small intestine itself produces a digestive juice which contains a protein- and several sugar-enzymes. These enzymes complete the process of digestion and the soluble substances formed, sugars and amino-acids, are absorbed into the blood vessels of the villi. They are then conveyed direct to the liver and thence to all parts of the body (p. 279). The fat enters the blood indirectly by means of the lymph (p. 283).

The waste food passes from the small intestine through the cæcum into the large intestine, so called because the diameter is considerably larger than that of the small intestine. The function of the large intestine, or colon, is merely to absorb water, and the undigested food or fæces pass on through the rectum and through the circular muscle at the anus. The cæcum, to which the appendix is attached, is always large in herbivorous animals such as the rabbit, and is presumably connected in some way with the digestion of cellulose, which is found very abundantly in plants. Cellulose is very resistant to chemical change, and, in fact, the mammalian intestine does not secrete an enzyme capable of dealing with it. The enzyme is produced by germs which are present in large numbers in the cæcum and the large intestine, and the sugars so formed from the cellulose are absorbed by the animal. The function of the appendix is not easy to understand as whatever function it had, one possibly connected with the digestion of cellulose, seems to have disappeared. In man, its hollow nature makes it very liable to be perforated or inflamed under certain conditions, and it is, of course, frequently removed surgically.

One of the differences in the digestive systems of man and the rabbit is the smaller size of the cæcum and the appendix. It is possible to follow the course of a meal through the intestine by introducing a small quantity of a salt of the metal bismuth into the food. This renders the food opaque to X-rays, and by means of X-ray cinematography, it is possible to see exactly what happens

to the food at various intervals after it has been swallowed. It gets into the stomach in a minute or two, but here some of the food stays for some hours. The more liquid part of the food is squeezed out into the duodenum at something like twenty seconds intervals and, in about four hours, the stomach will be empty, though the exact time depends on the nature of the food and the physical condition of the man. Another four to five hours will be spent in the small intestine. In the large intestine more time is taken and the waste will not reach the rectum until twenty to twenty-four hours after the meal.

Experimental Work on Digestion.—It is possible to demonstrate the hydrolysis of starch by ptyalin in the following manner. The mouth is rinsed two or three times with tepid water, and the extract of saliva is collected in a beaker. The extract is filtered and divided into two portions, one of which is boiled. To each portion in a test tube is added a little starch, and the tubes are kept at body temperature for about half an hour. It should now be possible to demonstrate the disappearance of the starch by means of iodine solution and the presence of sugar by means of Fehling's solution. An identical result may be obtained by using pancreatic extract instead of ptyalin. It may also be shown experimentally that gastric and pancreatic extracts contain enzymes which will dissolve small quantities of solid egg white cut into very small pieces.

The absorption of soluble substances in the small intestine may be very roughly demonstrated by the result of the following experiment. A jam jar is filled with water and a piece of parchment tied round the top in such a way that the parchment is in contact with the water. Into the hollow so formed is poured a mixture of a solution of glucose and starch " solution." After a few days it can be shown by means of iodine and Fehling's solution that the water in the jar contains the soluble compound sugar, but not the insoluble compound starch. The actual absorption of soluble food materials is vastly more complicated than in this experiment, and the details of the process are quite unknown.

CHAPTER XXX

THE BLOOD SYSTEM

THE circulation of blood through the hind foot of a frog or the tail or external gills of a tadpole may be seen under the low power of a microscope. The blood flows through tiny vessels or capillaries bringing various materials to the tissues of the foot. The vessels have extremely thin walls and are made visible by the flow of blood containing minute cells known as corpuscles, along them. The appearance of these vessels is shown in Fig. 211. The various substances present in the blood pass across the thin walls of the vessels to the regions where they are required. Food and other materials are brought to every tissue in the body by capillaries. They also collect waste substances for conveyance to the organs which deal with them.

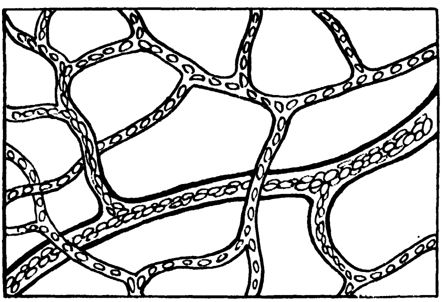


FIG. 211

Capillaries in the foot of the frog

Some animals, such as most of those which are microscopic, are small enough or thin enough to be able to do without a transport system to carry substances from one part of the body to another. Many comparatively small animals, such as crabs, worms and snails, have, however, a very elaborate blood system for this purpose. The system usually consists of a heart, comparatively thick-walled blood vessels called arteries, which carry blood away from the heart, and of comparatively thin walled veins, which bring blood back to it. The arteries branch repeatedly, and the blood finally flows through the capillaries and is collected up in the veins. The whole system is usually "closed," i.e. the blood flows in definite tubes or vessels from which it never emerges.

Blood System of a Mammal.—Soluble food substances are absorbed into blood vessels through the walls of the small intestine. These vessels are branches of a large vein termed the hepatic portal, which conveys the blood to the liver. Here, the food substances undergo certain changes. The blood carrying the food substances from the liver then runs into a very large vein called the inferior vena cava, which collects blood from the hind legs and from many other organs in the body cavity. The inferior vena cava discharges into the part of the heart called the right auricle. The blood from the head is also returned by important veins into the right auricle. Thus, the blood, which has flowed in capillaries through the organs of the body, is returned into the right auricle of the heart. (Fig. 212.)

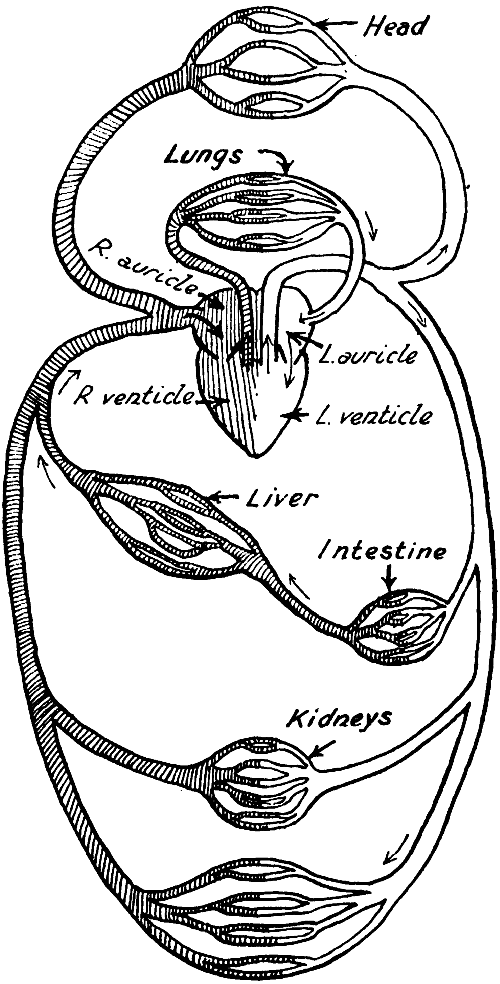


FIG. 212

Heart and circulation of mammal

The heart is a very complicated organ which is, in essentials, simply an enlarged blood vessel pumping the blood through the whole system. All the blood vessels except the capillaries have a layer of muscle in their walls, and in the heart this layer is particularly thick. The heart muscle is of a special kind, adjusted to continuous rhythmic contraction throughout the life of

the organism. The chief complication of the heart is due to the fact that it consists of two halves with no direct communication between them. Each half consists of two parts, an auricle and a ventricle, of which the latter has much the thicker wall and has the most work to do. The openings between each auricle and ventricle and the openings of the arteries out of the ventricles are guarded by valves in such a way that when the various chambers of the heart contract the blood can only flow in one direction.

The lungs serve as the channel of communication between the right and left sides of the heart. Thus the blood brought into the right auricle by the veins is squeezed into the right ventricle when the right auricle contracts. When the ventricle contracts, the valve between the auricle and ventricle prevents blood from flowing back into the auricle, and it is forced into the pulmonary artery, which supplies both lungs with blood. In the lungs the blood comes into contact with oxygen, which is taken up by the purple substance, hæmoglobin, contained in the red corpuscles, to form a bright red compound termed oxyhæmoglobin. This red, or oxygenated, blood, formed in the capillaries of the lungs, is collected up into the pulmonary vein, which takes it back to the heart, but to the left auricle. Actually, the two auricles contract at the same time. When this happens, the red blood is forced into the left ventricle. When the ventricles beat, it is forced into the main artery called the aorta, the opening into the left auricle being guarded by a valve. Thus the heart is a double pump, one supplying the lungs, the other the rest of the body. The aorta gives off many branches to the head and to all the organs of the body. The blood passes into capillaries, there loses its oxygen, and the blue or deoxygenated blood is eventually collected up into the veins which run into the right auricle.

The Discovery of the Circulation of the Blood.—This complicated system was not fully understood until the early seventeenth century, when the fact that the blood circulates round the body was demonstrated by the Englishman, William Harvey, physician to James I. His views were published in a small work in 1628. There had been no doubt that the heart was a pumping organ, and that blood was pumped by it into the arteries. The existence of capillaries had not, however, been suspected, and it was not known that blood returned to the heart in the veins. It is not possible to mention all Harvey's arguments, but two of the most important will indicate their general nature. The first

may be illustrated in the following manner. He estimated that the left ventricle pumped blood into the aorta at the rate of three and a half pints per minute. The amount of blood in the whole body is only about nine pints and it was therefore clear that every three minutes a quantity of blood had passed through the left ventricle which was greater than the total amount of blood in the whole body. These facts were strongly suggestive that the blood pumped from the heart must return to it again.

The second argument concerned the existence of valves in the veins. These valves, shaped like watch pockets, always face the direction of the heart and, consequently, if the blood flowed towards them, it would enter them and be stopped. Therefore Harvey argued that the blood in the veins must flow towards the heart, and he deduced from this the existence of the capillaries. Harvey tested his results experimentally by tying up the various blood vessels in a number of animals, and finding out in which places blood accumulated. Anyone may verify this point for himself. A bandage is first tied tightly round the arm or leg. If the blood in a large superficial vein on the side of the bandage away from the heart is now squeezed towards the heart the vein will become much lighter in colour. The reason is that the valves do not obstruct the flow of blood in this direction. If the blood is squeezed away from the heart the flow of blood is obstructed and the vein becomes more obvious.

The Pulse.—Arteries have thicker and more elastic walls than the veins, owing to the fact that arteries have to withstand the very considerable pressure set up by the beating of the heart. In most people the heart beats about 70 to 80 times per minute and gives rise to a wave of pressure, known as the pulse, which may be felt by placing the finger on any superficial artery, such as the radial artery in the wrist. The rate of beating of the heart is regulated by its nervous supply. Two nerves run to it, one slowing it down, the other quickening it up. The actual rate depends on the balance between the two. The flow of blood in the veins is uniform, owing to the fact that the capillaries present such resistance to arterial pressure that blood emerging from them is no longer affected by the individual beats.

Blood.—Blood is a pale straw-coloured liquid, consisting of an aqueous solution of salts, sugars, amino-acids, waste products due to metabolism, and many other substances. This solution is called the blood plasma. Floating about in it are two kinds of cells

termed corpuscles—red and white. The former are much the more numerous, there being over five million per cubic millimetre of blood as opposed to a few thousands of white corpuscles The red corpuscles are very tiny circular discs, hollowed out on each side (Fig. 213). The average life of a red blood corpuscle is about three weeks. They are formed in the red marrow inside the long bones, and are removed from circulation chiefly by the liver and the spleen. Red corpuscles are very distinctive in that when mature they do not have a nucleus. The importance of the red corpuscles is that, as previously mentioned, they contain solid hæmoglobin, a complicated substance composed of a protein and a substance containing iron. The hæmoglobin is an oxygen carrier. In other words, when in contact with much oxygen in the capillaries of the lungs the two substances combine together to form the compound oxyhæmoglobin. This compound is only stable in the presence of a considerable quantity of oxygen. When passing through the tissues, where the amount of oxygen is very much smaller, it breaks down into oxygen, which passes across the walls of the capillaries into the tissues, and hæmoglobin, which continues its journey back to the lungs. This oxygen-carrying mechanism is of the very greatest importance to a large and active animal. All vertebrate animals and also some invertebrates such as the earthworm and the lugworm possess hæmoglobin. Crabs and snails have an oxygen-carrier, hæmocyanin, which contains copper and not iron.

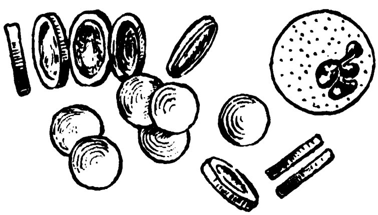


FIG. 213
Red corpuscles. One white corpuscle is also shown

The white corpuscles are considerably larger than the red and each contains a nucleus. The shape of each corpuscle is irregular and is constantly changing. In fact this corpuscle is in many ways similar to the microscopic animal Amœba (p. 365). There are many different types, but the most important kind is concerned with changes which happen to diseased or injured parts of the body. These white corpuscles are capable of taking into their own substance both disease germs and microscopic pieces of injured tissue, and of destroying them. Whenever tissue becomes inflamed, it is a sign that white corpuscles have assembled there and are carrying on their activities. These activities are often accompanied

by a rise in the temperature of the body, which is thus a sign of the activity of the white corpuscles. Pus consists very largely of the remains of white corpuscles which have perished.

Lymph.—As has already been pointed out, the blood is contained in closed tubes, and does not come into actual contact with the cells of which the body is composed. In reality some fluid soaks through the walls of the capillaries, thus bathing the tissues and bringing to them a supply of food substances and oxygen. The lymph, as this fluid is called, is thus a middleman between the blood and the tissues. It is collected into special ducts which return the lymph to the blood system. In this way waste and other substances find their way into the blood system.

Summary of the Functions of the Blood.—Any substance which has to be transported from one part of the body to another must obviously be carried by the blood. Food substances in solution and oxygen combined with hæmoglobin are distributed in this way, and waste materials are conveyed in solution to the kidneys.

Many glands discharge their products into the blood-stream. These substances, which are called hormones or chemical messengers, are transported in this way to the scene of their activity. A good example is the insulin produced by the pancreas (p. 276). The secretion of pancreatic juice is stimulated by another hormone called secretin, which is formed from the duodenal wall after the acid mixture of gastric juice and food is passed into it. The secretin passes into the blood-stream and stimulates the pancreas to secrete. Further reference to hormones will be made in Chapter XXXVI.

The clotting of blood plugs up wounds, unless, as in the case of damage to a large artery, the flow of blood is too strong to allow clotting to take place. The blood solidifies after an interval of a few minutes, owing to the formation of a meshwork of minute fibres of a protein called fibrin, in which the corpuscles become entangled. The liquid matter remaining after the blood has clotted is called serum. This clotting is a complicated process and is not yet completely understood. Many factors are concerned, notably the formation of a substance, possibly an enzyme, from the damaged vessel, and the presence of calcium salts in the blood. The importance of clotting is made clear by the serious nature of the disease termed hæmophilia, in which the blood fails to clot for a long time. The slightest injury may thus continue to bleed for hours, even days.

CHAPTER XXXI

THE SOIL

IT is the usual practice to plough cultivated land before the severe conditions of winter arrive, partly because the bad weather hinders the work, but also because in another way it helps a great deal. Before the seed is sown in the spring it is desirable that the lumps of soil should be broken up into much smaller particles. In this case the breaking-up process is carried out by such natural agents as rain and frost. Rain batters the soil and when the water between the particles of soil is frozen it expands, thus causing the lumps to break up.

The process described above is termed weathering. Land masses are subject to a continuous process of denudation, and rocks of all kinds are subjected to various natural processes which break them up until ultimately the particles so formed pass down the rivers as silt and sink to the sea floor. Frost and the mechanical action of rain, rivers and glaciers, are the chief, but not by any means the only, factors in the weathering of land masses. The early stages may be seen in any mountainous district. The rocks are full of crevices, and the mountain torrents full of boulders which gradually decrease in size as the stream flows down the valley. The only plants which can grow in the more exposed places are lichens, which are very thin and leathery.

Origin of Soil.—Soil is formed by the weathering of rocks. Rain and frost are the chief factors in the earliest stages, when small crevices are formed and small flakes and particles detached. Lichens are then able to grow, dust accumulates round them and other plants begin to grow. These plants die and the decaying remains add to the soil, which now becomes black. These stages may be verified in any quarry (Fig. 214) or cutting where all the stages may be seen from the solid rock below, passing through many intermediate stages to the black soil above. Some of our richest soils are soils of transport in that the particles are derived

from the rocks much higher up the valley and are deposited nearer the sea when the current slows down as in periods of flooding. Alluvium formed in this way is fine grained and contains much vegetable material, and is consequently very fertile.

FIG. 214

Photograph showing transition from rock into subsoil and soil by weathering (Hythe Beds, Great Chart, Kent)

Constituents of Soil.—Many of the constituents of garden soil can be traced back to the rocks from which the soil was derived. Thus sand is a direct descendant of the mineral quartz, not much changed in constitution, but merely in smaller particles, the silica being sometimes yellowed by compounds of iron. Clay is the product of weathering of certain minerals called felspars, which are commonly distributed rocks. China clay, which is used in pottery, is a special type of clay found, among other places, in Cornwall, and is derived from the breakdown of granite. Soils formed from limestone and chalk are naturally rich in salts of lime, and soils formed from other sources may be deficient in this

respect. The most important constituents for plants are the black material called humus, which is the product of the decay of animal and plant bodies in the soil, and water, which is normally held as a film round the soil particles.

The percentages of the various materials present may be determined in the following manner. A sample of soil is burnt in a weighed crucible until the weight is constant, and the water and the humus are both driven off, the total amount being determined by the loss in weight. By heating a further sample of the same soil to 100° C. on a water bath the water alone is driven off and the humus remains. The loss in weight gives the weight of water in the sample. The soil minus water and humus is then ground up in a mortar and put through a series of graded sieves in order to separate the large sand grains from the very fine clay particles. A simpler method is to put the dried soil into water, when the larger particles, namely the sand grains, will immediately sink to the bottom and can be dried and weighed. A rough guide to the amount of chalk is provided by the amount of effervescence when a little concentrated hydrochloric acid is added to a sample of the soil.

Properties of Soil Constituents.—The particles of sand are very large compared to the very fine clay particles. The latter fit together so tightly that neither air nor water can pass quickly through clay. These properties may be investigated by setting up funnels with clay and sand filters and timing the rate of flow of water through them. On the other hand the channels between the particles are so small that water rises by capillarity in clay to a greater extent than in sand. For these reasons clay becomes very waterlogged and contains insufficient air for the growth of the roots of plants. This condition may be improved by the liberal application of lime. Lime is also an important plant nutrient ; it is, too, an alkali and neutralizes the acidity of many soils. Typical crops grown on clay are wheat, mangolds, beans and cabbages. On sandy soils potatoes, turnips and rye are frequently grown. Chalk, like sand, readily allows water and air to pass through it. Chalky soil may be very fertile ; clover, lucerne and barley are typical of this type of soil. Humus, however, retains water, as it consists of very fine particles. The most useful agricultural soils are loams, which are mixtures of sand and clay, with the usual admixture of humus. The latter is only present in the top eighteen inches or so of soil, and is responsible for the black colour. From the humus are formed the salts which plants absorb from the soil.

Consequently the blacker the soil the better. Soil below this level is coarser and lighter in colour and is termed subsoil.

Soil Organisms.—The production of carbon dioxide from moist soil indicates that it contains living organisms too small to be seen by the naked eye. This gas is not produced by soil which has been heated, the organisms having been killed by the heat. There are several millions of these germs or bacteria (Chapter XLI) per cubic cm. of soil, and they take part in many important processes. There are in addition many larger animals, including insect larvæ such as wireworms (larvæ of the click beetle) and leather jackets (larvæ of the daddy-long-legs), both of which feed on the roots of plants. Millipedes also feed on plant roots, but centipedes on the other hand are useful, since they destroy many harmful types of insect.

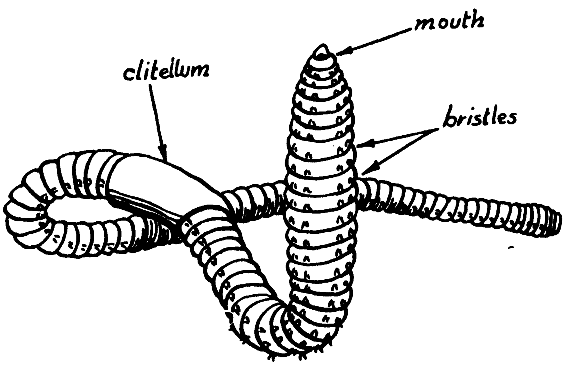


FIG. 215
The external features of the earthworm

There are also many insects such as ants which do not seem to be harmful as long as they are not too numerous.

A very important animal in the soil is the earthworm, which burrows by passing soil through its intestine, feeding on the organic débris it contains, and depositing the undigested remains as worm casts on the surface. Worms are present in such numbers that there are tens of thousands to the acre, and their activity in bringing soil from lower levels to the surface is thus very important. It has been calculated that worms may be responsible for bringing as much as eighteen tons of soil to the surface over one acre in a single year. Their activities are largely responsible for the structure of soil, which should, when in good condition, crumble in the hand. The crumbs of soil consist of larger particles stuck together by the

clay and humus. Worms also bring humus into the soil by their habit of dragging leaves and other vegetable material into their burrows. The external features of the earthworm are shown in Fig. 215. The body is divided into about 180 segments. Movement is effected by the longitudinal and circular muscles of the body wall, the animal obtaining a hold by means of bristles, of which there are four pairs per segment. The swollen region known as the clitellum secretes a case in which the eggs are deposited.

Osmosis.—The parchment used in an experiment on digestion described on page 277 allows both water and dissolved substances to pass through it. Such a membrane is said to be permeable. Some membranes, such as a sheet of waterproof material, are impermeable and allow neither water nor dissolved substances to pass through them. Other membranes are semi-permeable and allow water but not dissolved substances to pass through. In the apparatus shown in Fig. 216 a semi-permeable membrane is tied round the open end of the vessel inside the beaker. The most convenient membrane to use is an artificially prepared collodion membrane. The dilute glucose solution in the beaker is thus separated from the more concentrated solution inside the vessel by the membrane. Under these conditions water passes through the membrane into the inner vessel and the coloured liquid in the long tube rises until the concentration of the sugar on both sides of the membrane becomes equal. The flow of water across a semi-permeable membrane under these conditions is termed osmosis.

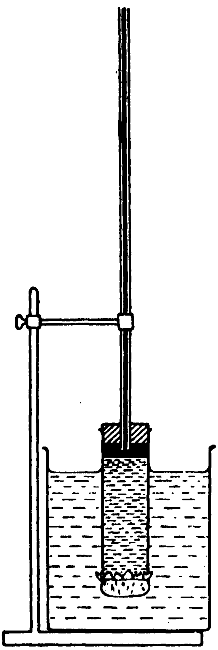


FIG. 216

The effects due to osmosis may be observed if suitable isolated plant cells are placed in sugar solution of varying concentration. Suitable cells for the purpose are those of Spirogyra (p. 370) or those of the hairs on the stamens of Tradescantia. Failing these, the cells seen in a thin section of beetroot may be used. All these cells consist of a cellulose cell wall which is freely permeable, a very thin layer of protoplasm which is semi-permeable, and a vacuole containing coloured cell sap which is an aqueous solution of various sub-

stances. In Spirogyra the cell sap is colourless, but the protoplasm contains green structures which make it visible. If these cells are placed in a sugar solution which is more dilute than their own cell sap, water will flow from the solution into the vacuole and the cell will become distended with water, i.e. in botanical language, turgid. If, on the other hand, the solution is more concentrated than the cell sap, water flows out of the vacuole into the solution. The protoplasm then shrinks from the cell wall, and the cell is said to be plasmolysed. A 10 per cent. to 15 per cent. sugar solution is sufficient to plasmolyse most cells. These phenomena play a large part in many plant mechanisms. The rigidity of seedlings is almost entirely due to the turgidity of the cells.

The Absorption of Water by Plants.—Most plants absorb all their water from the soil and none from the atmosphere. The soil water normally exists as a continuous film round the soil particles. The absorbing organs are termed root hairs and are situated immediately behind the growing tips of the young roots. New root hairs are constantly being formed as the tip continues to

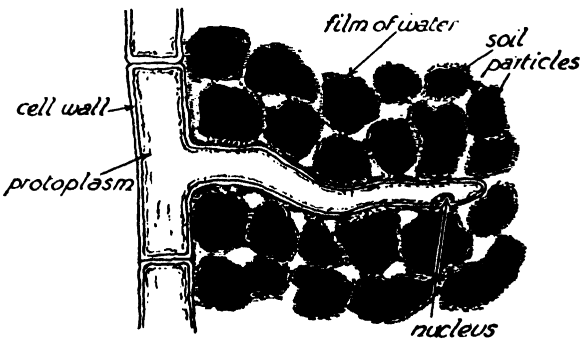


FIG. 217
Root hair

grow. Each root hair (Fig. 217) is part of a cell on the surface of the root, and contains a large vacuole. The cellulose cell wall enters into very intimate contact with the fine particles in the soil. The root hairs are usually microscopic, but in the mustard seedling they are particularly large and easily visible to the naked eye. Soil water is a dilute aqueous solution of various salts derived chiefly from the humus. The cell sap of the root hair is a stronger

solution of various substances, including sugars and salts. These solutions are separated from one another by the cell wall, which is permeable, and by the protoplasm of the root hair which is semi-permeable. Water will therefore flow by osmosis into the root hair, and this provides the mechanism of the absorption of water by plants. The conducting tissue is in the centre of the root and the water passes through several layers of cells by osmosis before the vessels and tracheids are reached. Neither these cells nor the root hairs become fully turgid otherwise the flow of water would stop.

The Absorption of Salts.—The soil solution is so dilute that the standard method of reference to the concentration is in terms of *x* parts of, for example, potassium per million parts of water. The solution can be extracted from the soil by crushing or by suction, and a chemical analysis can be made. This reveals that the salts concerned are, among others, chlorides, sulphates, phosphates and nitrates of such metals as calcium, magnesium, sodium, potassium and iron. If the protoplasm of the root hairs is assumed to be absolutely semi-permeable, these salts could not enter the plant. The protoplasm is clearly not absolutely semi-permeable, but the mechanism by which they do enter is by no means fully understood.

Water Cultures.—The salts necessary for the full development of a plant may be discovered by water-culture experiments, in which the plant is grown in various solutions containing mixtures of different salts in different concentrations. It has been found that a plant will grow quite normally in the following solution :

Distilled water	1 litre.
Potassium nitrate	1·0 gm.
Magnesium sulphate	0·25 gm.
Iron (ferrous) phosphate	0·5 gm.
Calcium sulphate	0·25 gm.
Sodium chloride	0·5 gm.

Once the complete water-culture solution has been discovered, it is possible to use it as a control in order to find out the effects of leaving out certain substances from the complete solution. Thus, if the seedling is sufficiently young or has been kept continuously in the dark, it will be found that it will not turn green

in the absence of iron or magnesium. The accompanying photograph (Fig. 218) shows a number of water-culture experiments using various solutions, in which the results can clearly be seen.

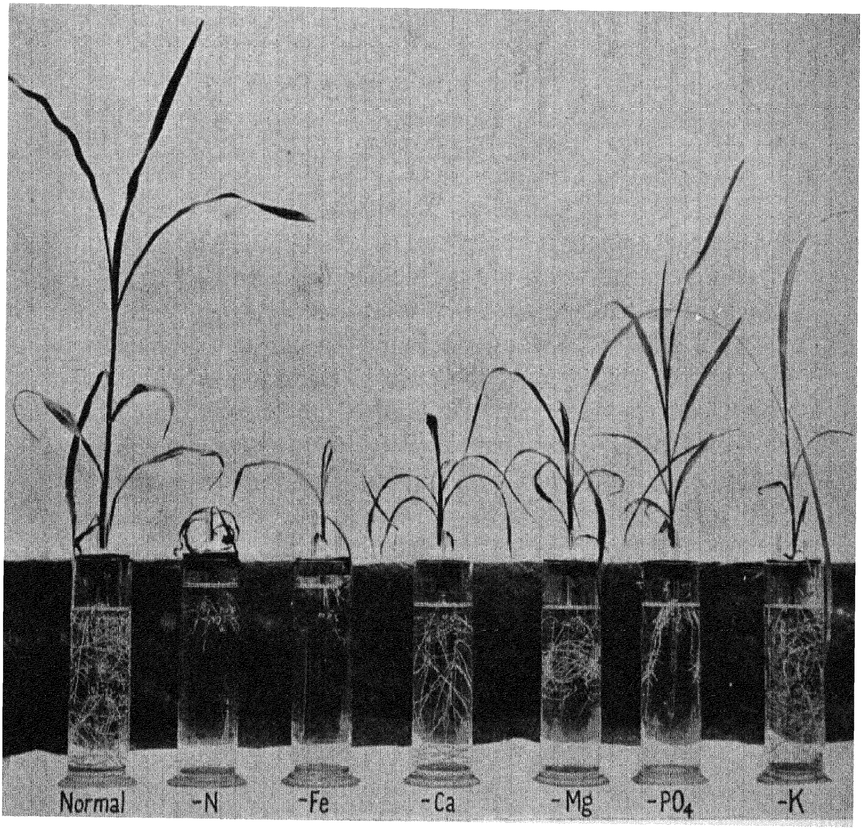


FIG. 218

Water culture of Maize. Normal = complete culture solution; – N = nitrogen absent; – Fe = iron absent; – Ca = calcium absent; – Mg = magnesium absent; – PO_4 *= phosphorus absent; – K = potassium absent*

CHAPTER XXXII

PHOTOSYNTHESIS

CHEMICAL analysis of a plant reveals the presence of the elements contained in the normal water-culture solution, together with many which are not absolutely essential, but which are almost always present. One other element, namely carbon, is always present. Yet carbon is not present in the complete water-culture solution, and the plant is able to grow without it being there. It must clearly come from another source, probably the air. The only constituent of the air from which carbon could possibly come is carbon dioxide, but this gas is only present to the extent of 0·03 per cent. It might seem doubtful whether this supply could be sufficient for the whole plant kingdom. The answer can only be supplied by experiment.

Effect of Absence of Carbon Dioxide.—The obvious way in which to tackle this problem is to attempt to grow a plant such as a Primula in an atmosphere devoid of carbon dioxide. This is quite an easy matter, as there are several substances which absorb this gas and so remove it from an enclosed space. Most convenient to use is a solution of sodium hydroxide, a little dish of which is enclosed with the plant which is the subject of the experiment under a bell jar. The plant used should have been kept in the dark for some twelve hours previous to the experiment. A leaf of the plant is removed, decolorized by boiling in methylated spirits, and soaked in iodine solution. A blue-black colour would indicate the presence of starch, but in this case no starch should be detected. If the plant is to obtain sufficient oxygen, air must be allowed to enter, as in Fig. 219, where it is seen that the air which enters must pass through a tube containing particles of solid soda lime, which also absorbs carbon dioxide. (Soda lime is a mixture of lime and sodium hydroxide.) Any ill effects the plant might suffer might be due to conditions other than lack of carbon dioxide, so it is essential to set up a control experiment, in which a similar plant is

enclosed in a bell jar which has no cork and no sodium hydroxide solution. The two bell jars should now be exposed for some hours to bright sunlight. If a leaf of the plant in the control experiment is removed, decolorized and soaked in iodine solution, the leaf will turn bluish black, clearly showing the presence of starch. A leaf removed from the plant which has not been in contact with carbon dioxide will give a negative result if the same test is carried out. Starch contains carbon ; it seems, therefore, that plants which

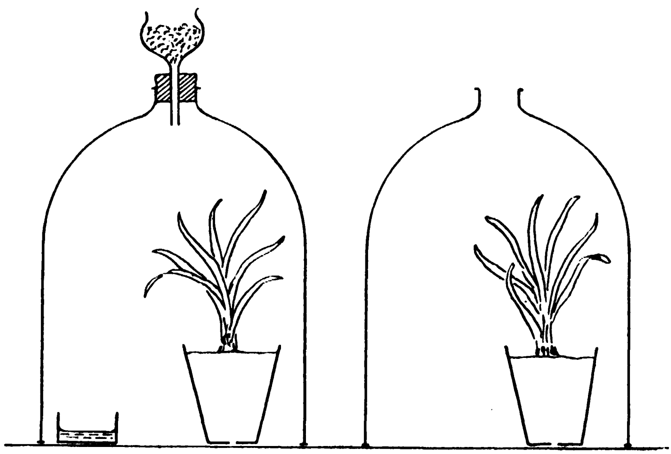


FIG. 219

have access to carbon dioxide form starch in their leaves, for the plant had no starch in its leaves when the experiment began.

Experiment and control may be combined in the same piece of apparatus if a leaf still attached to a plant is fixed by means of a split cork half in and half out of a tube containing potassium hydroxide. When this leaf is removed after exposure to bright sunlight, decolorized and put into iodine, only the half which remained outside the tube will go blue.

Effect of Absence of Sunlight.—Starch has been shown to form in a green leaf well within a second of exposure to bright sunlight. Light therefore must also be a factor in the building up of starch. This can be demonstrated by testing for the presence of starch in a plant which has been kept in the dark for some time. A striking modification of this method is to fix, by means of two thin plates of glass and a clamp, a black stencil with the word " starch " left unblacked (Fig. 220) over a leaf still attached to a

plant which has been in the dark for twenty-four hours. Here also is experiment and control in the same piece of apparatus for, on exposure to sunlight, only the part of the leaf immediately

FIG. 220

underneath the unblacked letters will receive any light and be able to form starch. On applying the iodine test, the word starch should be written across the decolorized leaf in blue letters.

Effect of Absence of Chlorophyll.—The green colouring matter, chlorophyll, also plays a part in building up starch. It is convenient to use the variegated leaves of maple, holly, privet or laurel to demonstrate the importance of chlorophyll. These leaves are coloured green and yellow, and only the green part contains chlorophyll. The leaves, still on the plant, are exposed to bright sunlight for several hours, decolorized and tested with iodine. Those parts of the leaf which were green will turn blue, the others remaining uncoloured.

Chlorophyll is a mixture of four pigments, which can be extracted from the green parts of plants by solution in alcohol and many other organic liquids. Two of these pigments contain magnesium, which explains why this element is necessary for its formation. A trace of iron is also necessary. Plant tissues which are not exposed to light will not become green; indeed the chlorophyll will soon break down in the dark as, for instance, when an area of grass is covered by a plank for some time. The grass is then said to be in an etiolated condition and will recover once again if exposed to the light. The other two pigments are called carotin and xanthophyll, both of which occur by themselves quite commonly in plants. Carotin, for instance, is so called because it is the yellow pigment found in carrots.

Evolution of Oxygen.—The apparatus shown in Fig. 221 consists of a beaker full of water containing a few twigs of Canadian pondweed. The twigs are covered by an inverted funnel supported in such a way that the water in the beaker and that under the funnel are continuous. Over the stem of the funnel is an inverted

test-tube, full of water. When the apparatus is put into bright sunlight or very bright artificial light bubbles of gas are given off by the plant and accumulate at the top of the test-tube. On testing with a glowing splinter the gas is found to be oxygen. If the water in the beaker has been previously boiled to expel all dissolved gases including carbon dioxide, and a layer of oil is poured over the surface to prevent any carbon dioxide from entering, no oxygen is evolved. It appears, therefore, that oxygen is evolved during the process of photosynthesis.

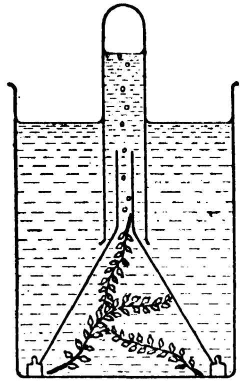


FIG. 221

Structure of a Green Leaf.—A transverse section of a leaf is shown in Fig. 222.

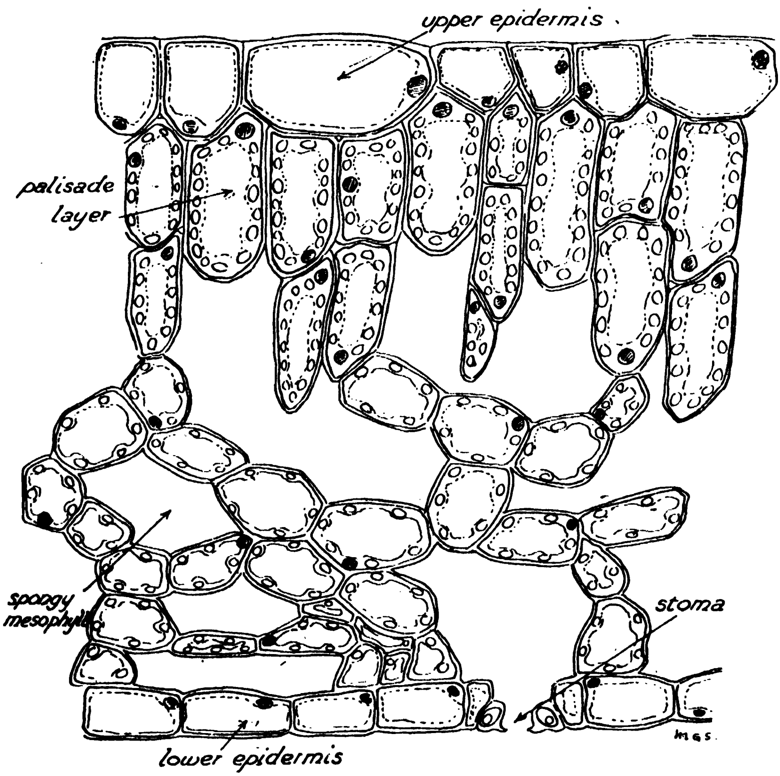


FIG. 222

Transverse section of a leaf

The veins of the leaf consist of xylem and phloem and link up with those of the stem. The chlorophyll is formed at the surface of small bodies called chloroplasts which are distributed in varying numbers in the different tissues of the leaf. The palisade layer, which is just under the upper surface of the leaf, has most of them, and it is here that most of the starch-making goes on. The layer below the palisade has fewer chloroplasts, and there are much larger air spaces between the cells. The protective layer, or epidermis, on the upper and lower surfaces, is covered by a water-proof cuticle. The

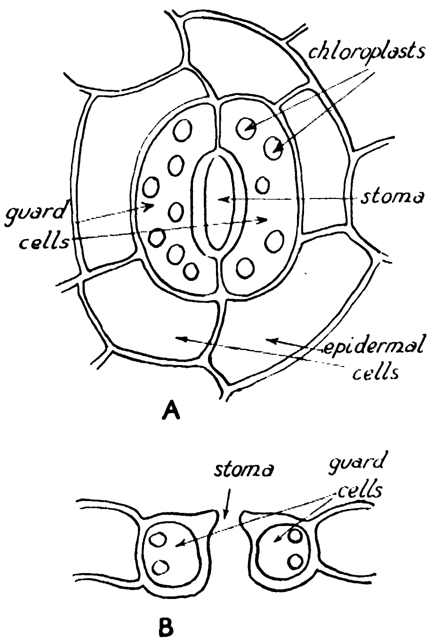


FIG. 223

A. Surface view of stoma.
B. Transverse section of stoma

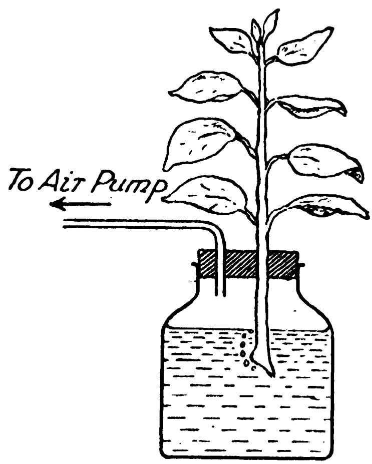


FIG. 224

epidermal cells, with the exception of very numerous pairs of cells termed guard cells, do not contain chlorophyll. Between each pair of guard cells is a minute pore termed a stoma (Fig. 223). Air slowly passes through the stomata into the air spaces between the cells, and the carbon-dioxide supply of the leaf is obtained in this way. All the air spaces of the leaves and stems of plants are linked up to form an internal atmosphere. If the apparatus shown in Fig. 224 is connected to a filter pump, the suction draws in air through the stomata and a stream of bubbles emerges from

the cut end of the stem, showing that the air spaces of stem and leaf form a continuous system.

Photosynthesis.—Some of the factors in starch-making, such as carbon dioxide, light and chlorophyll, have been discussed, but there are many others which are not so tangible or so easily demonstrated. For instance, water is a raw material in this process, but it is very difficult to demonstrate it. The chemistry of starch-making is not at all clear. At any rate, the raw materials, carbon dioxide and water, are known, and the products, sugars and starch, are known, but there is as yet no satisfactory account of all the intermediate stages. The matter may be summed up by saying that carbon dioxide, which comes in through the stomata, and water, which comes in through the roots, are built up into sugar, which is immediately turned into starch, the most convenient storage product.

It can be demonstrated that chlorophyll absorbs certain rays of light, notably the red and the blue. There is nothing remarkable about that, as nearly all substances absorb some rays. What is remarkable, in fact unique, is the use which is made of the absorbed light. The synthesis of a complex substance like sugar from such simple substances as carbon dioxide and water, requires a great deal of energy, which is given out in the reverse process. It is in this way that the sunlight is used. It supplies the energy, in the form of light, which is required in the synthesis of sugar. The process is thus known as photosynthesis. Oxygen is formed in photosynthesis as a waste product, but it is a highly important product as it replaces that used up in animal and plant respiration. Thus, the amount of oxygen in the air remains more or less constant. Photosynthesis can thus be represented by the equation:

$$\text{carbon dioxide} + \text{water} = \text{sugar} + \text{oxygen.}$$

Fats and Proteins.—These substances are just as necessary to plants as to animals, for they are constituents of the actual living matter. They are formed inside the plant, the fats, by a series of reactions, from the sugar, the proteins by combination of the sugar with nitrates taken in from the soil. The latter process is thought to occur chiefly in the leaves, the nitrates being converted into the related and more active salts called nitrites, which then combine with the sugars to form simple intermediate substances, subsequently built up into proteins. These reactions are all greatly accelerated by enzymes.

Translocation and Storage of Foodstuffs.—When leaves containing starch are allowed to remain on the plant overnight and tested for starch on the following morning it is discovered that this substance has disappeared from the leaves. It is turned into sugar again by diastase and conveyed to other parts of the plant. The starch of a potato tuber is formed as sugar in the leaves, temporarily converted into starch, reconverted into sugar during the night and conveyed to the tuber, where it is turned once more into starch. When the potato tuber germinates the starch is converted once more into sugar. The fats and proteins undergo corresponding changes and are stored in various parts of plants. Soluble foodstuffs, such as sugar, are transported from one part of the plant to another by means of the sieve tubes.

CHAPTER XXXIII

RESPIRATION OF PLANTS AND ANIMALS

FOOD substances are used by organisms partly as raw material for the building up of new protoplasm and partly as a source of energy. They may also be stored before being used for either purpose. Organisms set free energy by the slow combustion (p. 185) of food substances in every cell of their bodies. In this way every cell is enabled to carry on all the activities, such as growth, which show that it is alive. The whole process, or respiration as it is termed in living organisms, is directly comparable to the changes which occur in a coal fire or in an internal combustion engine. The changes may be expressed in a word equation, thus:

Fuel + oxygen = simpler substances + ENERGY.

The carbon present in the fuel is oxidized to carbon dioxide and, as the fuel contains hydrogen, water is also formed. The essential feature of combustion or respiration is this disintegration of the fuel, involving the formation of simple substances which are of no use and which may be compared to the exhaust gases of an internal combustion engine.

In the case of the organism, the fuel consists of the simple soluble substances derived from the food, namely sugars, amino-acids, glycerine and fatty acids. Sugar is the most widely used of these compounds, so that the word equation for respiration may be written thus:

Sugar + oxygen = carbon dioxide + water + ENERGY.

In this way the chemical energy of the sugar is converted into forms of energy which enable the activities of the organism to proceed. That respiration in animals and plants is fundamentally the same process is shown by the experiments described below. It is probable, however, that the intermediate breakdown products are different.

The Necessity of Oxygen.—In experiments on plant respiration, it is convenient to use seeds, which, since they do not contain any chlorophyll, simplify any possible difficulties due to starch-making activity at the same time. When seeds are soaked in water, they begin to respire very actively. Dry seeds can be used very profitably as a control in many of these experiments, since they contain so little water that respiration proceeds so slowly as to be undetectable. It is easy to show that respiring seeds use up oxygen. Two boiling-tubes are used, one containing dry barley grains, the other, moist grains. After they have been left for a day or two, a lighted taper plunged into the tube containing dry seeds will continue to burn (if the taper has been introduced carefully), while in the other tube it will immediately go out, showing that all the oxygen inside the tube has been used up.

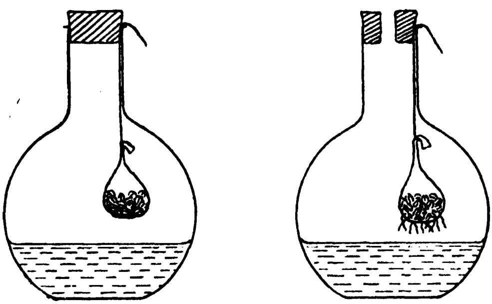


FIG. 225

The experiment illustrated in Fig. 225 is designed to show that moist barley grains will not germinate in the absence of oxygen. The seeds are suspended into a flask from which all oxygen has been absorbed. The absorbent used for oxygen is an alkaline solution of an organic substance called pyrogallol, which immediately turns dark brown when it comes into contact with oxygen or air. Oxygen is prevented from entering the flask by means of a cork. In this experiment it is advisable to set up a second experiment as a control, in which a similar flask and similar seeds are employed, the only difference between the two flasks being that, in the control, the seeds have access to the oxygen of the air. This second flask would contain, therefore, water instead of pyrogallol and would have no cork. After a few days, the seeds in the control experiment will have germinated and their roots will have

grown down into the water, while there will have been no visible result at all in the other flask.

Either of these experiments may be modified to show that animals too need oxygen. Fish, or the eggs of fish or frogs, will die if they are put into water which has been boiled to expel all dissolved gases. It is common knowledge that animals such as frogs, mice or cockroaches will die if confined in a small space and have no access to air. It can be shown that little if any oxygen remains after an experiment of this nature. Death will be considerably more rapid if pyrogallol is used to absorb the oxygen.

The Evolution of Carbon Dioxide.—The apparatus illustrated in Fig. 226 is designed to show the production of carbon dioxide by respiring seeds. The seeds are soaked, put into a flask and a current of free air sucked over them by means of a filter pump. The latter is a piece of apparatus so designed that when it is attached to a tap and the tap is turned on, the falling water draws air through the whole apparatus. The flask through which the air first passes contains potassium hydroxide solution, the U-tube contains soda lime. These ensure that no carbon dioxide is

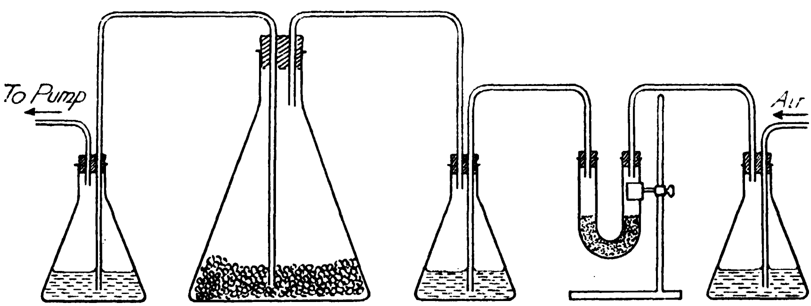


FIG. 226

present in the air supplied to the seeds. To show that no carbon dioxide is present another flask is used containing lime water. The lime water does not turn milky. Actually, of course, the amount of carbon dioxide in the air is so small (0·03 per cent.) that there is hardly likely to be any difficulty in this respect. The air emerging from the flask is shown to contain carbon dioxide, for it turns the lime water in the end flask milky. This experiment may be used to demonstrate the fact that green parts of plants also evolve carbon dioxide continuously, but if this is desired the experiment must

be carried out in the dark. If the experiment were carried out with green leaves in sunlight, a good deal of the carbon dioxide evolved in respiration would be used immediately in photosynthesis, and complications would ensue.

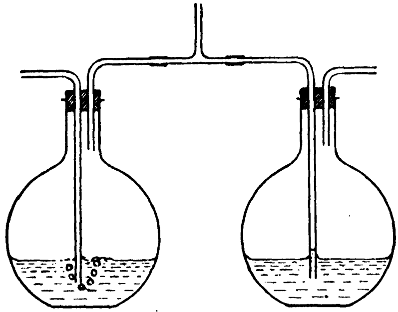


FIG. 227

This experiment may be modified in the case of an animal by substituting some mice, frogs, insects or earthworms for the seeds. The production of carbon dioxide in our own respiration may be demonstrated by using the apparatus shown in Fig. 227. Both flasks contain lime water. When the tube between the two flasks is sucked, air bubbles enter the flask on the left. When the experimenter blows into the tube, the air from his lungs enters the flask on the right. The lime water in the flask on the right quickly turns milky, but that in the left flask does not turn milky for a long time. This shows that the air emerging from the lungs contains much more carbon dioxide than that which entered.

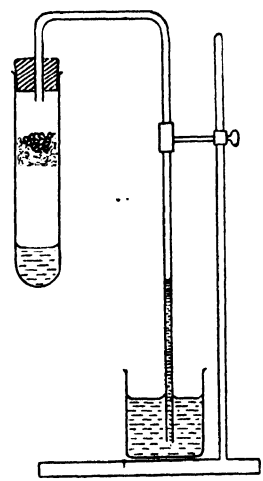


FIG. 228

It has thus been shown that plants need oxygen and that they also evolve carbon dioxide. It is possible to demonstrate these two facts in the same experiment, illustrated in Fig. 228. The large tube contains potassium hydroxide and a pad of cotton-wool supporting a few soaked pea-seeds. A volume of air is thus enclosed between the surface of the potash and that of the coloured water in the dish. The pea-seeds gradually absorb the oxygen from this air. Carbon dioxide is evolved by the seeds, but this gas is absorbed by the potash, so that the net result is the creation of a partial vacuum in the vessel, and the coloured water is sucked upwards. A variation may be made in which the potash in the large tube is replaced by water. The water will not absorb the carbon dioxide evolved, and the level of the coloured

water in the tube will depend on the relative volume of oxygen absorbed and carbon dioxide evolved. When the material being respired consists of carbohydrates, as in this case, these volumes are equal, and there is, therefore, no change in the level of the liquid at all. Another variation may be made by using dry instead of moist seeds. These are, to all intents and purposes, not respiring at all, so that, once again, there will be no change in the level of the tube. The same result is obtained in all three of the above experiments if animals such as earthworms are substituted for the seeds.

The Evolution of Energy.—Some of the energy liberated in respiration is liberated as heat. That heat is evolved by respiring plants can be shown by half filling a thermos-flask with moist pea-seeds and comparing the temperature of the seeds with that of dry seeds put into a similar flask at the same time. A thermos-flask is used in order that little of the heat produced by the seeds can escape. The thermometer is held in place by a plug of cotton-wool, through which air can slowly diffuse. After a few days there will be a difference in temperature of several degrees Centigrade between the contents of the two flasks. The same experiment could be carried out with any cold-blooded animals, such as earthworms or snails, which could easily be packed into a thermos-flask.

Photosynthesis and Respiration.—Many people are puzzled by the fact that the gases oxygen and carbon dioxide are concerned in both photosynthesis and respiration. The confusion only arises in the case of plants, since there is, of course, no photosynthesis in animals. Respiration, involving the taking in of oxygen, the liberation of energy and the evolution of carbon dioxide and water as waste products, must necessarily go on continuously throughout the lives of both plants and animals. The photosynthesis of plants can be compared to the process of feeding in an animal, not only in that it is not continuous but that it does literally provide the plant with food. The difference is that animals take in their food in the form of carbohydrates, fats and proteins, while plants, feeding on very much simpler substances which would be of no use at all to an animal, must build them up themselves. The point of confusion is that the raw materials used by the plant in photosynthesis are exactly the same as the waste products produced by the complete oxidation of the food substances in respiration, namely, carbon dioxide and water. In other words, the material which is respired in order to provide the plant with the

necessary energy is built up by the plant in photosynthesis which, it must be remembered, can only take place in certain conditions. This does not mean that the mechanism of one process is merely the mechanism of the other in reverse—far from it. The two processes are entirely different, with entirely different intermediate stages, as yet imperfectly known in both cases.

In bright sunlight the green plant is taking in carbon dioxide from the air, and sugar is being formed continuously in the cells containing chlorophyll. Respiration is also going on too—oxygen being taken in from the air, and carbon dioxide evolved. Doubtless nearly all of this carbon dioxide is promptly used again in photosynthesis, and the oxygen set free in the latter process used in respiration. When the sunlight is bright, photosynthesis will be the more rapid process, but later it will stop entirely and respiration will not be masked by it. It is often stated that green plants should be removed from a bedroom at night because they absorb some of the oxygen needed by the human occupant. This is quite true, but the quantity is so minute that the practice is quite unnecessary.

Breathing Mechanisms.—If respiration takes place in every cell of the bodies of organisms, the cells must have an adequate supply of food substances and of oxygen. Plants do not move about and thus require much less oxygen than animals. They rely entirely on the entry of air through the stomata and lenticels into the air spaces which form a continuous internal atmosphere throughout the living tissue of the plant. The fact that roots do not thrive in soil deficient in air indicates that some oxygen probably enters the root dissolved in the water absorbed by the plant.

Animals which move about rapidly need a great deal of energy. Air enters the body through a moist membrane, which in microscopic and many small animals is the surface of the body. In such animals as Amœba (p. 365), Hydra (p. 391) and jelly-fishes this rather slow process is quite adequate for the needs of the animal. Such animals have therefore no special respiratory organs, nor have they a blood system for the transport of food substances and oxygen. The earthworm is a bulkier animal in which the skin is the respiratory surface and is very well supplied with blood vessels. This animal also has the same oxygen carrier as vertebrate animals, namely hæmoglobin. This is by no means general among invertebrates, though snails and crabs have a similar substance called hæmo-

cyanin, which is a compound of copper. This is, however, not as efficient as hæmoglobin, which is responsible for the transport of some forty times as much oxygen as would otherwise be taken into the blood.

It is not always convenient for the whole surface of an animal's body to be so permeable, yet respiratory organs must present a large area to the air or water, otherwise there would not be an adequate supply of oxygen. Thus, many aquatic animals have feathery outgrowths of their body, known as gills, which are well

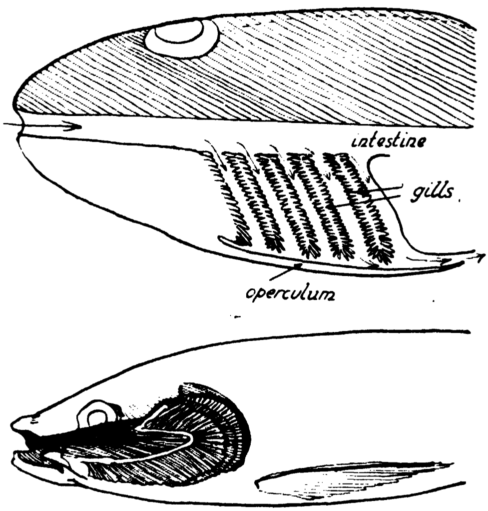


FIG. 229

Gills of fish. The upper drawing represents a horizontal section through a fish, the lower a herring from which the left operculum has been removed

supplied with blood vessels. Examples of animals with gills are the crab, whelk, mayfly nymph, many marine worms and, of course, fish. The body wall in these animals, apart from the gills, is impermeable to water and dissolved substances. The gills of fish (Fig. 229) are the folded linings of the gill-slits which open from the gullet to the exterior. Water enters at the mouth, flows over the gills and emerges from behind the bony plate or operculum, which protects the gills. Oxygen dissolved in the water passes across the gill membrane into the blood system. The breathing mechanism of insects is unusual. Air enters the body through a

series of apertures, termed spiracles, along each side of the body, and reaches each cell independently of the blood along a series of air tubes known as tracheæ (Fig. 230). The air in the tracheæ is renewed in most insects by alternate contraction and expansion of the abdomen.

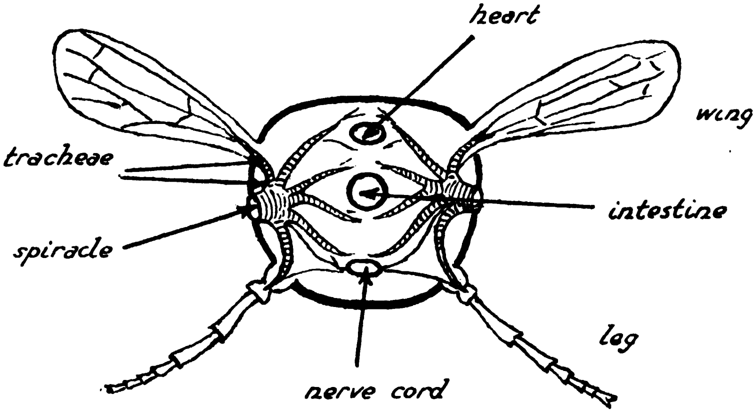


FIG. 230

Transverse section through the thorax of an insect (After Packard)

The vertebrates, excluding the fish, breathe by means of lungs, which lie in the body cavity. Air is alternately sucked into and expelled from them in a variety of ways in the different groups. The structure of the lungs increases in complexity in ascending from the frog to mammals, reaching a climax in man, where the total internal surface area capable of absorbing oxygen is something like one hundred and twenty square yards.

Respiration of Man.—The air breathed in enters the lungs through the windpipe which divides into two bronchi, one leading to each lung. Each divides repeatedly until each tube enters an air sac, the walls of which are lined with microscopic pockets called alveoli (Fig. 231). The oxygen and other gases, though not in actual contact with the blood in the capillaries, are separated from it only by the very thin walls of the alveoli. The lungs are protected by membranes called the pleuræ.

The windpipe or trachea is kept from collapsing by rings of cartilage in its walls. It swells at its upper end into the larynx or Adam's apple, and opens into the back of the throat. The nose is protected by bone, the nasal passages lying immediately

above the hard roof of the mouth. As the air comes through the nostrils, dust and germs are filtered from it and its temperature rises until it is nearer that of the body.

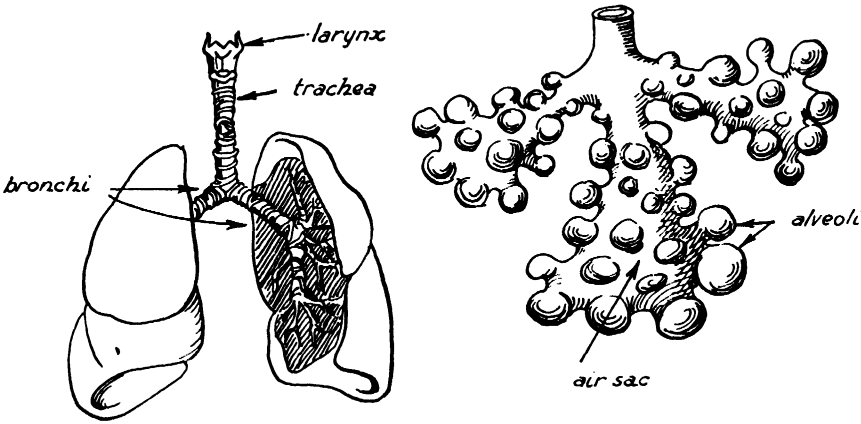


FIG. 231
The structure of the lungs

Air is taken into and expelled from the lungs by movements of the ribs and of the diaphragm. The ribs are hinged on to the backbone and are pulled upwards and outwards by the muscles between them during inspiration. At the same time, the diaphragm, which is a dome-shaped sheet of muscle separating the chest from the abdomen, flattens out. Both these movements, which normally occur about seventeen times a minute, enlarge the cavity of the chest, with the result that the air pressure in the chest cavity is reduced and the air pressure outside the body forces air into the lungs, which expand. In expiration, the ribs are pulled back again, the diaphragm relaxes, the cavity of the thorax returns to its former size, and the lungs are squeezed, with the result that some of the air they contain is expelled. In this way the supply of air to the lungs is constantly renewed, and there is always plenty of oxygen to be absorbed. The apparatus shown in Fig. 232 represents a model of the chest. When the rubber diaphragm is pulled downwards,

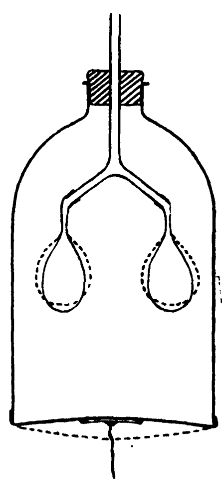


FIG. 232

the air pressure on the bladders which represent the lungs is diminished and air is forced into them through the opening which connects them to the atmosphere. When the rubber returns to its normal position, the "lungs" collapse and air is driven out into the atmosphere.

CHAPTER XXXIV

ORGANISMS AND WATER

WATER is an extremely important substance to both plants and animals. Animals obtain water both directly and from their food, of which most constituents contain large percentages of water. In addition, the water formed as a waste product in respiration constitutes about one-seventh of the total water income of the body. Water is lost as moisture from the lungs, as perspiration, as urine, and also in the fæces. It is most important that there should be a balance between the rate of water income and the rate of water loss.

Waste Products.—Carbon dioxide is expelled from the lungs in the expired air. The air entering the lungs is composed of roughly 79 per cent. nitrogen, 21 per cent. oxygen, 0·03 per cent. carbon dioxide (excluding a varying percentage of water vapour); that leaving the lungs consists of 78 per cent. nitrogen, 16 per cent. oxygen and 4 per cent. carbon dioxide. The carbon dioxide formed in the tissues in respiration is taken up by the lymph and passes into the blood. It is probable that the red corpuscles play a large part in its conveyance to the lungs. Purple blood has been shown to be more efficient for this purpose than red. The rate of breathing depends upon the amount of carbon dioxide in the blood. If there is too much of this gas in the blood or in the lungs, the respiratory centre in the brain is affected and the muscles responsible for breathing receive a nervous impulse which stimulates them to greater activity. Respiratory movements thus proceed more quickly than normal during muscular exercise. The moisture in the breath is derived from the moist internal lining of the lungs.

Animals break down proteins in respiration as well as sugars and fats, and thus waste products containing nitrogen are formed as well as carbon dioxide and water. The chief of these is a substance called urea, formed mainly in the liver. This and other compounds are passed into the blood-stream and are carried to

the kidneys (Fig. 233), which are embedded in the dorsal wall of the body cavity. Each consists of a large number of tiny coiled tubes very well supplied with blood. The blood and dissolved substance are filtered through the enlarged blind end of each little tube. Some substances in the blood, such as glucose, are too valuable to lose, and these are reabsorbed by the tubule as the filtered fluid passes through. The urine containing urea and other substances is collected up into a pair of long tubes, one from each kidney, both opening into the neck of the bladder.

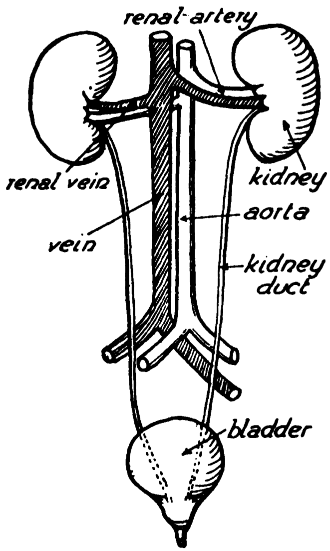


FIG. 233
The kidneys and associated structures

The chemical mechanisms of the body are very delicately adjusted and it is essential that the composition of the blood, except for normal variations in food and other substances, should be constant in composition. The function of the kidneys may thus be defined as the regulation of the composition of the blood.

Temperature Regulation.—The water lost in sweating plays a very important part in the maintenance of a constant internal temperature in mammals. Cold-blooded animals such as worms, insects, fish, frogs and reptiles liberate heat in respiration, but have no mechanism to prevent losing it. The internal temperature of these animals is therefore only a few degrees higher than that of their surroundings, and they are completely at the mercy of external conditions. Unless they live in particularly sheltered places, or in water, they are either killed or put out of action by the low temperatures of an English winter. In birds and mammals the loss of heat is prevented by an external layer of feathers or hair.

A constant internal temperature is just as important to mammals as blood of constant chemical composition, and some system of regulation is essential. In man the constant internal temperature is 98·4° F. Vigorous muscular movement, or a high external temperature lead to conditions in which the internal temperature

may tend to rise. In this case the diameter of the superficial blood vessels in the skin is increased by a nervous mechanism, the skin becomes flushed, and the increased flow of blood leads to a loss of heat to the external medium. The sweat glands (Fig. 234) in the skin also receive an increased flow of blood in this way, and they secrete a fluid which passes along ducts to the surface of the body, and there evaporates. Evaporation involves a loss of heat (p. 86) and sweating is thus a method of removing heat. The sweat

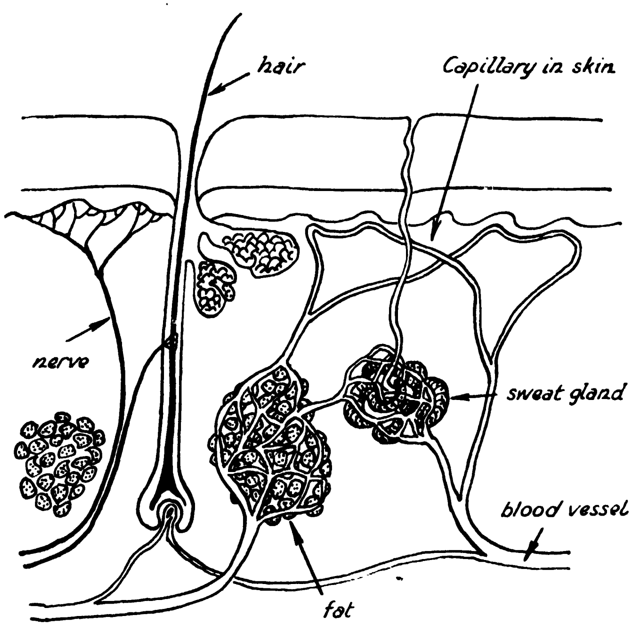


FIG. 234
Transverse section of human skin

contains waste substances which remain on the skin when the liquid has evaporated, and sweating is thus also a method of excretion. Under ordinary conditions as much as a pint of water may be lost in this way in a day. If the atmosphere is very moist as well as hot, evaporation is naturally very slow and intense discomfort is the result. Heat is also lost from the body in the breath, and in various other ways.

In cold weather more food must be eaten in order to produce additional heat. Muscular exercise is also necessary; in fact, shivering is an involuntary nervous reaction which leads to muscular

activity. The superficial blood vessels now constrict and blood is kept from the skin and the sweat glands. Warm-blooded animals are obviously much more independent of their surroundings than those which are cold-blooded, but they must have relatively large quantities of food to keep up the temperature. Some warm-blooded animals, such as hedgehogs, hibernate in the winter, but this is due to shortage of food, in this case, insects. They are not put out of action by the low temperature and sometimes emerge on warmer days to look for food. In the case of the hedgehog a store of fat is accumulated in the autumn and gradually disappears during the course of the winter.

Water Balance of Animals.—The water content of the body as well as the chemical composition of the blood is controlled by the kidneys. The quantity of urine depends upon the amount of water entering the body and also upon the amount of water lost from the sweat glands.

Loss of Water from Plants.—If a green plant is left under a dry bell jar for a day or two the internal surface of the glass will soon be covered by drops of water which have condensed on it. If a quantity of white anhydrous copper sulphate is left in the bell jar when the experiment is set up, the colour will change to blue, thus showing that water vapour has been produced. The water vapour might come from the soil, but, if the pot and soil are both covered by waterproof material, leaving only the plant projecting through it, the same thing will still happen. The only way to stop it is to remove the leaves from the plant. The leaves apart from the stomata are covered by a more or less waterproof layer or cuticle. It seems probable, therefore, that the winter vapour escapes from the leaf through the stomata.

It is possible to confirm this idea in several ways by making use of the fact that, in a normal terrestrial leaf, the stomata are practically confined to the lower side. There are various exceptions to this rule, notably in vertical leaves such as those of the iris. If a leaf loses too much water, so that its cells are no longer turgid, it loses its rigidity and is said to wilt. If the water vapour does escape through the stomata, it ought to be possible to stop a leaf from wilting by plugging up the stomata on the lower side. An experiment of this nature may be carried out by hanging up in a window four ivy leaves which have been treated with vaseline in various ways. In all cases, the cut end of the leaf stalk should be plugged with vaseline to ensure that no water is lost in that way.

One leaf is smeared with vaseline on the upper side, one on the lower side, one on both sides and the other not at all. When all the stomata are free, water escapes quickly and the unvaselined leaf wilts first. As there are a few stomata on the upper side, the vaseline there stops a little water vapour from escaping, but the leaf vaselined on the lower side retains its water for a considerably longer period. The leaf vaselined on both sides wilts last of all.

The above experiment shows that the stomata are indeed the paths of water loss. The same conclusion may be reached by using a substance which changes colour in the presence of water or water vapour. A solution of cobalt chloride is pink, but if a small quantity of the solution is poured on to a piece of white filter paper and the latter dried in an oven, the colour changes to blue. On adding water, the colour changes back again to pink. If a small piece of this blue paper is placed on each side of a leaf, which may be either detached from or still attached to the parent plant, and the papers kept in position by glass plates bound together by rubber rings, it will be found that the paper on the lower side will turn pink much more quickly than that on the upper side, showing that more water vapour is being lost on the side where the majority of the stomata are to be found.

Quantity of Water Lost.—The loss of water through the stomata of green plants is called transpiration. Plants lose a very considerable quantity of water in this way. In the case of large herbaceous plants, the quantity may amount to a pint or more a day, while large trees with countless delicate leaves will probably lose many gallons in warm weather. It is possible to determine the amount of water lost by a small plant in three ways —firstly, by absorbing the water given off by means of such a substance as calcium chloride, and finding the gain in weight of the latter; secondly, by finding the loss in weight of the whole plant over a given period of time; and, thirdly, by determining the volume of water lost and assuming that it is equal to the volume of water transpired. Of the three, the second is usually considered to be the most accurate, as the loss in weight of the whole plant is comparatively large and easy to find accurately, and the other changes in weight, due to photosynthesis and respiration, so small by comparison that they need not be taken into account. This method is most easily applied to a potted plant, which can be left on the scales of a large transpiration balance, and the changes

in weight noted from time to time. The pot itself and the soil must be covered by waterproof material so that no water escapes from the soil, otherwise a very serious error would be introduced into the calculation.

The apparatus known as a potometer—literally, drink measurer —is often employed to determine the amount of water transpired by a cut shoot. Various forms of it are used, but the essential

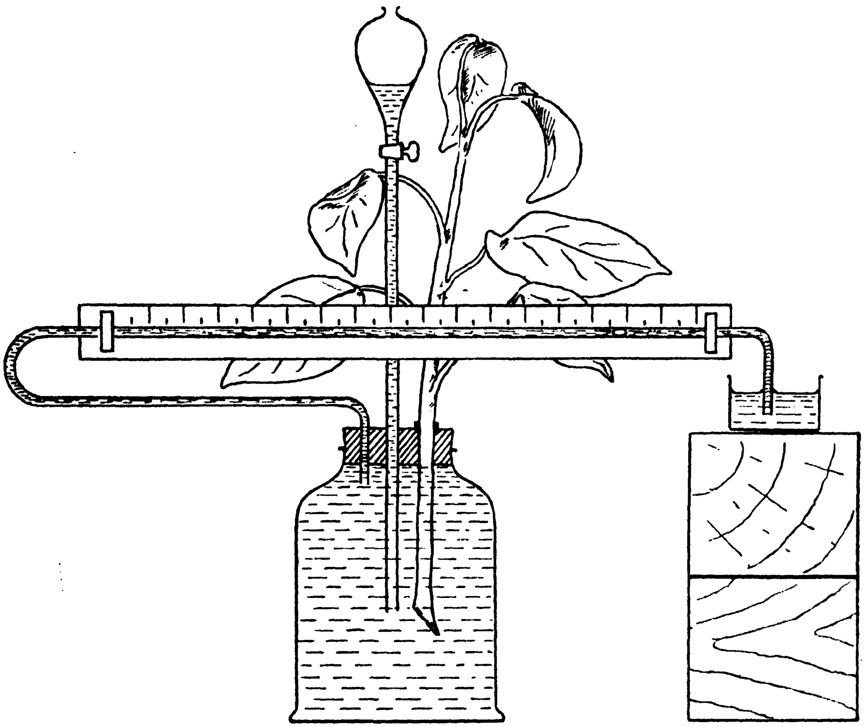


FIG. 235
Potometer

principle is that the basal part of a shoot dips through a cork into a tube or jar of water which is calibrated in some way, and the volume of water absorbed in a given time is measured. In the form shown (Fig. 235), the calibrated part of the apparatus consists of a capillary tube which dips at one end into the jar, and at the other end into a dish of water. When the experiment begins and the whole apparatus is full of water, a bubble is introduced into the tube by means of the application of a piece of filter or blotting-

paper, and the progress of the bubble along the tube towards the jar is noted at intervals. The volume of water absorbed during the period of time chosen is given by the distance moved by the bubble, multiplied by the sectional area of the tube. The water in the funnel occupying the third hole through the cork of the jar is used to send the bubble back again to the far end of the tube when necessary. The value of this method is chiefly comparative, and may be used to compare the quantity of water lost under varying conditions of light intensity, temperature and air currents.

If the structure of the leaf is borne in mind, it will be seen that, as long as the stomata are open, water is bound to evaporate from the moist walls of the mesophyll cells of the leaf. The water vapour passes out through the stomata, and the drier the atmosphere, the more quickly will the water vapour escape. Any conditions which bring about this result, such as an increased temperature or wind, which blows away the water vapour from the immediate neighbourhood of the stomata, will quicken up the rate of transpiration. The factors which influence the opening and closing of the stomata will, too, have a great effect on the rate of water loss.

Water Balance in Plants.—The assumption that the amount of water absorbed by a shoot is approximately the same as that transpired is, of course, by no means always true. The rate of each process depends on a number of factors which are related but not the same in each case. Thus, absorption depends on the amount of water in the soil, the temperature of the soil, the nature of the soil, the degree of turgidity of the root hairs and so on, while transpiration depends on the humidity of the air, wind, temperature of the air, the structure of the leaf, number and arrangement of stomata, and the light intensity. When there is plenty of water in the soil and the sun is not too hot, the two processes may be approximately equal, but, in the absence of rain, a really hot day produces a much greater loss of water from the leaves than the plant can really afford to lose. The stomata have no control over this excessive loss, and they do not close until the plant has wilted and all the cells in the leaf have lost their turgor. Plants which live in deserts and very dry places would lose more water than they could afford if they could not cut down the loss in some way or other. Such plants nearly always have a relatively small area of transpiring surface compared to their bulk. Thus, in many cases such as gorse, broom and the pine, the leaves are comparatively small. Often the stomata are in little depressions or grooves,

and may be surrounded by hairs. Sometimes the plant is succulent and the leaves very much reduced, as in cacti.

The Flow of Water through a Plant.—The loss of water from the leaves is unavoidable, but this water is replaced from the soil and there is thus a constant stream of water flowing through the plant. The salts which are dissolved in the water are brought up by the transpiration current, as it is called, to the leaves and are caught up into the plant's metabolism, while the water is lost through the stomata. It can be convincingly shown in a simple way that the water flows upwards only in that part of the vascular bundles, termed the xylem, which consists chiefly of vessels and tracheids. If a plant, such as a dead nettle, is put into a coloured solution, such as eosin or even red ink, it will be found that the red solution ascends the stem into the leaves and a section of the stem will show that only the xylem is stained red. As a woody plant becomes older, more leaves are produced, and a new layer of xylem is added to the outside of that already existing every year (p. 249). In plants which have a great deal of xylem, such as trees, only the younger outer xylem functions as water-conducting tissue, the central heart wood becoming blocked and hardened for mechanical purposes.

Opening of Buds.—In winter the light is not sufficiently strong for photosynthesis to be carried on. Leaves are thus useless during this season and many plants do not retain them. The transpiration current stops in winter, and must start again before the buds can open. The increased temperature of spring seems to be the trigger which produces activity in plants which have been more or less dormant through the winter. The roots begin to grow and absorption begins. A force known as root pressure is an important factor in the commencement of the ascent of sap in the spring. Its existence may be demonstrated in some plants by means of an apparatus consisting of the stem of the potted plant, e.g. a geranium, cut across a few inches above the ground, connected to a manometer by means of rubber tubing. After a few days, if the plant has been well watered, the fluid in the limb of the manometer nearest to the plant will be forced downward. This apparatus must be set up under water.

Excretion in Plants.—Plants respire chiefly carbohydrates and occasionally fats. Hence, if these substances are oxidized completely, their only excretory products will be simply carbon dioxide and water, both of which are valuable to plants. Conse-

quently, plants do not need a system such as animals have to deal with nitrogenous waste products. Indeed, the supply of nitrogen in the soil is sometimes so low as to cause plants serious difficulties, and none is wasted. -

CHAPTER XXXV

ANIMAL MOVEMENT

THE mammalian skeleton serves a threefold purpose. It protects many vital organs such as the brain, the heart and the lungs, and provides a rigid framework to support the body (Fig. 237). Most important of all it is jointed in such a way that the contraction of muscles attached to various parts of it brings about movement either of parts or of the whole body. The skeleton consists of two types of tissue, bone and cartilage. The latter, also known as gristle, is seen under the microscope to consist of groups of cells separated by a clear tough material which is secreted by the cartilage cells themselves from material supplied by the blood (Fig. 236). A section of the outer region of a long bone shows that in this case the cells are arranged in layers (Fig. 236). The material between the cells is very hard and consists largely of calcium phosphate. The cells of the inner region are arranged in longitudinal cylinders, each enclosing a central cavity in which run blood vessels and nerves. The cavity in the centre of long bones is filled with red marrow which gives rise to red and white blood corpuscles. Thus both cartilage and bone are living tissues.

The Skeleton of the Rabbit.—The skeleton to be described is that of the rabbit, but the description will apply in essentials to all mammals. Part of the human skeleton is shown in Fig. 237. The backbone consists of a number of separate rings of bone termed vertebræ. Each vertebra consists of a solid piece of bone called the centrum with an arch of bone above it enclosing and protecting the spinal cord. Each vertebra has various spines and projections to which muscles are attached. There are also special surfaces by means of which each vertebra is connected to its neighbours. Between the vertebræ are discs of cartilage which act as shock absorbers. The vertebræ of the different regions of the backbone vary in structure according to their function. There are, with few exceptions, seven neck vertebræ in mammals, designed to allow

very free movement. The first two of these are interesting in that they are responsible for the nodding and turning movements of the head, to be described in a later paragraph. The twelve vertebræ of the thoracic region have special surfaces for the articulation of the ribs, the movements of which play an important part in breathing. The ventral ends of most of the ribs are firmly fused

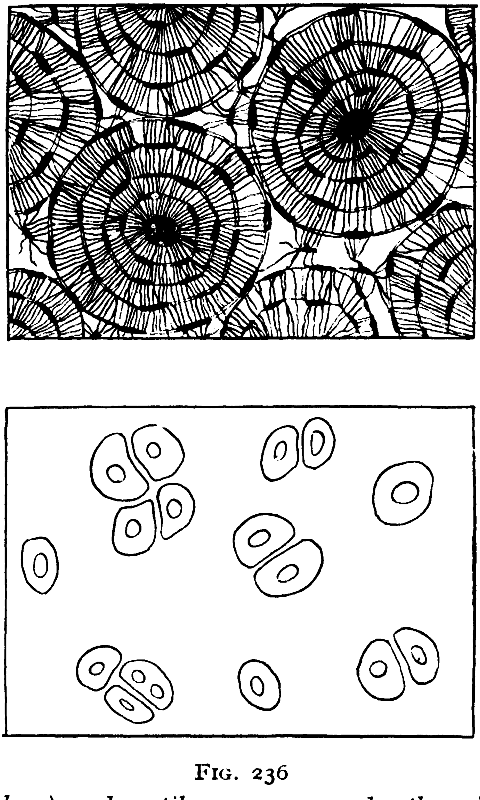


FIG. 236

Bone (above) and cartilage as seen under the microscope

to the breastbone or sternum ; the lungs and heart, which lie inside the " box " so formed, are thus well protected. A number of pairs of ribs, two in man, are not attached to the sternum and are called " floating ribs." To the large lumbar vertebræ are attached many of the muscles of the back. The vertebræ to which the pelvis is attached are themselves fused together to give greater strength. The tail vertebræ are numerous. In man the structure

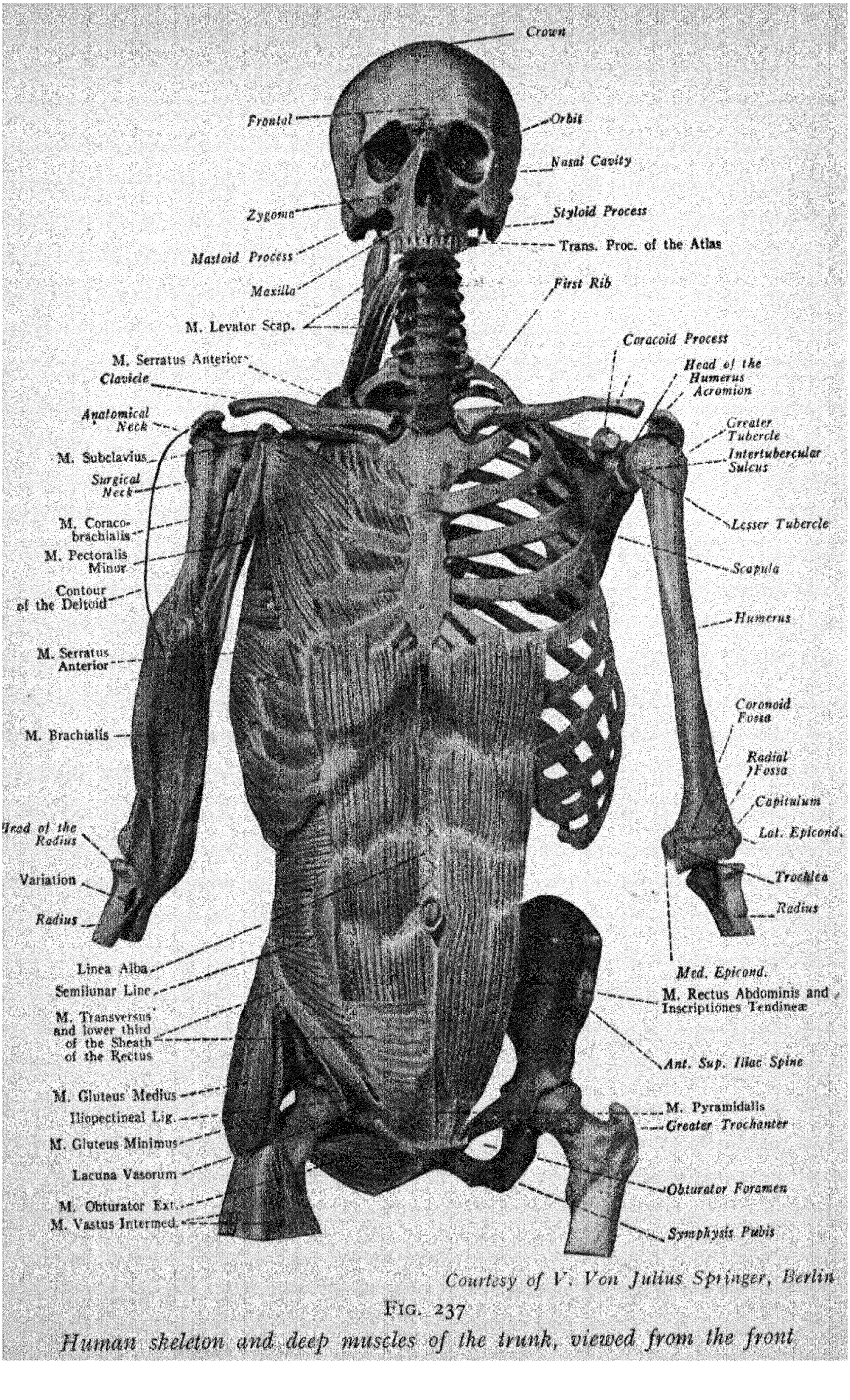


FIG. 237

Human skeleton and deep muscles of the trunk, viewed from the front

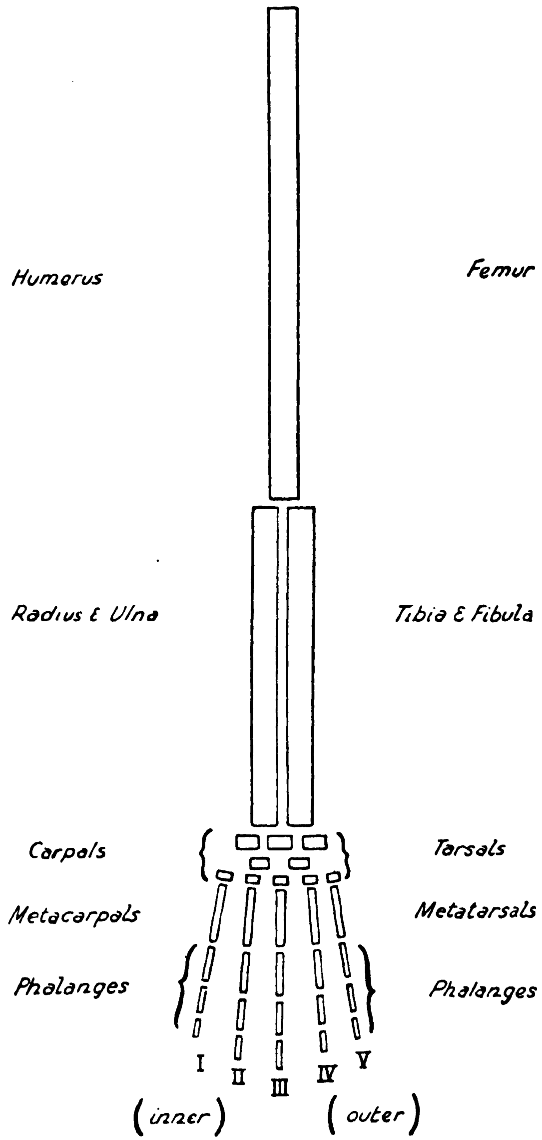


FIG. 238

termed the coccyx at the base of the spine represents the tail vertebræ of our ancestors.

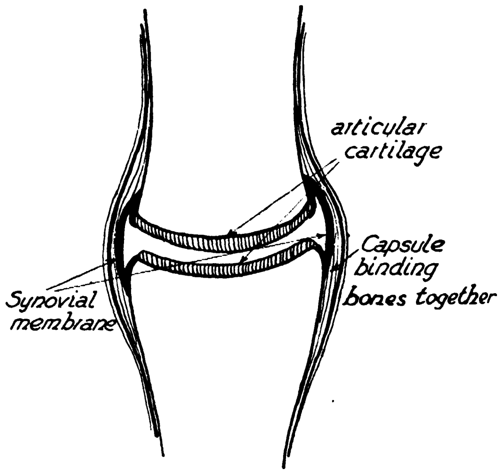
Each pair of limbs is connected to the backbone by an incomplete girdle of bone. Each girdle consists of three bones on each side.

In the pelvis these bones, the ilium, the ischium and the pubis, meet in the socket into which the thigh bone fits. The pubes are fused together ventrally in the middle line. The ilia, which project forwards, are firmly fused to the vertebral column, so that the whole structure is very strong, a very important point as most of the weight, and in man the whole of the weight, has to be supported on it. The shoulder girdle also consists essentially of three bones on each side, though one, the coracoid, is reduced to a process on the shoulder-blade or scapula. The third bone is the collar bone, fused at one end to a process of the scapula and at the other to the front end of the breastbone. The collar bone is absent in such mammals as the horse, which do not use their forelimbs otherwise than for locomotion. The socket for the bone of the upper arm is on the scapula.

Both limbs are constructed on the same plan, as seen in Fig. 238. At the knee and elbow there is a hinge joint, and there are two bones in both the lower leg and forearm. Great flexibility in the ankle and wrist is ensured by the presence of a comparatively large number of small bones. In man, the forearm can be twisted through 180°, as the radius which, in the prone position, twisted over the ulna with its lower end on the inner or thumb side, can be rotated so that the radius and ulna lie side by side, the radius still on the thumb side.

Joints.—A joint is a junction between two bones and may be immovable, slightly movable or freely movable. In the last case, the two bones are kept in position by fibres known collectively as the capsule (Fig. 239). The ends of the two bones, which move on one another, are each covered by cartilage which prevents grating. The synovial membrane, which is the internal lining of the cavity enclosed by the capsule and bones, secretes a syrupy fluid, which lubricates the movements of the bones concerned. In some cases, pads of a special kind of cartilage are present, which more definitely assist the movement of the bones. In the knee, for instance, there is such a pad on each side of the top of the shinbone. They are easily jerked out of position by twisting movements, and may have to be removed surgically.

The Skull.—The skull is made up of a fairly large number of bones which are fused together or interlocked. The lines of interlocking can readily be seen and are called sutures. The main mass of the skull consists of the cranium, which encloses the brain. The spinal cord enters the cranium through a large opening at its



SECTION OF A SIMPLE JOINT
FIG. 239

posterior end. On each side of this large opening is a projection, which fits into a socket on the atlas, which is the first vertebra in the neck. The name of this vertebra refers to the mythical giant who supported the world on his shoulders. Nodding movements of the head are performed directly on the atlas, but in turning movements the atlas and the skull are locked together, and both move as a single unit on a part of the axis, which is the second vertebra in the neck. Internally, the cranium is terminated in front by a perforated partition, through which pass nerves from the brain to the nose. The front part of the skull is concerned with the nose, which has special bones to protect it, as also has the ear just behind the cheek bone. The eyes are sunk into special sockets called the orbits. The skull is completed by the upper jaw, which is firmly fused to the under side of the anterior region. The nasal passages pass between the upper jaw and the remainder of the skull. The hinder end of the lower jaw fits into a socket just in front of the ear.

Muscles.—Muscles constitute what is usually termed the flesh of an animal; when we eat lean meat we eat muscle. The individual fibres making up the muscle are unique, in that they can become shorter and fatter when stimulated by the nerve which supplies them, and can later revert to their original shape and size. In other words, they are elastic and can contract and expand.

When an individual fibre is examined under the microscope, alternate light and dark bands are seen (Fig. 240). These fibres are relatively large, and many cells enter into the composition of each fibre. The only nuclei which can be distinguished are those of the sheath. Muscle fibres are nearly always found in small bundles, which are in turn grouped together into large bundles, each covered by a sheath. The whole muscle is attached at one end, called its origin, to a relatively immovable piece of the skeleton, and at the other end, called its insertion, by means of a tendon, to a piece of the skeleton which can move freely on a joint. Thus, when the muscle contracts, the movable bone is pulled in the same direction.

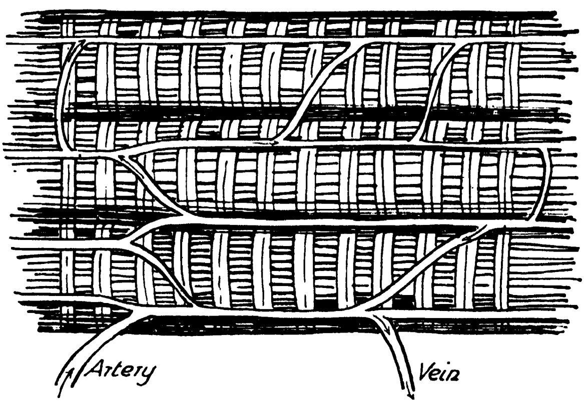


FIG. 240
Striated muscle fibres with capillaries between them
(*After Keith, " Engines of the Human Body," published by Williams & Norgate, Ltd.*)

In these movements, the movable bone plays the part of a lever in lifting a weight (p. 30). The whole process can readily be examined in the case of movements of the forearm, in which relatively few muscles are concerned (Fig. 241*b*). The important muscles are two in number, one occupying the lower side of the upper arm, the other being very prominent on the upper side. The latter muscle, the biceps, originates by two heads on the scapula and is inserted on the near end of the radius. When it contracts the scapula cannot move, so the lower arm is raised. The biceps can also bring the forearm into the supine position by rotating the radius so that the palm of the hand faces forwards. The forearm does not merely fall back into its original position,

but is pulled back by the triceps muscle on the opposite side. Muscles are usually arranged in pairs in this way. The forearm obviously acts as a lever (Class III, p. 32), lifting up the hand and

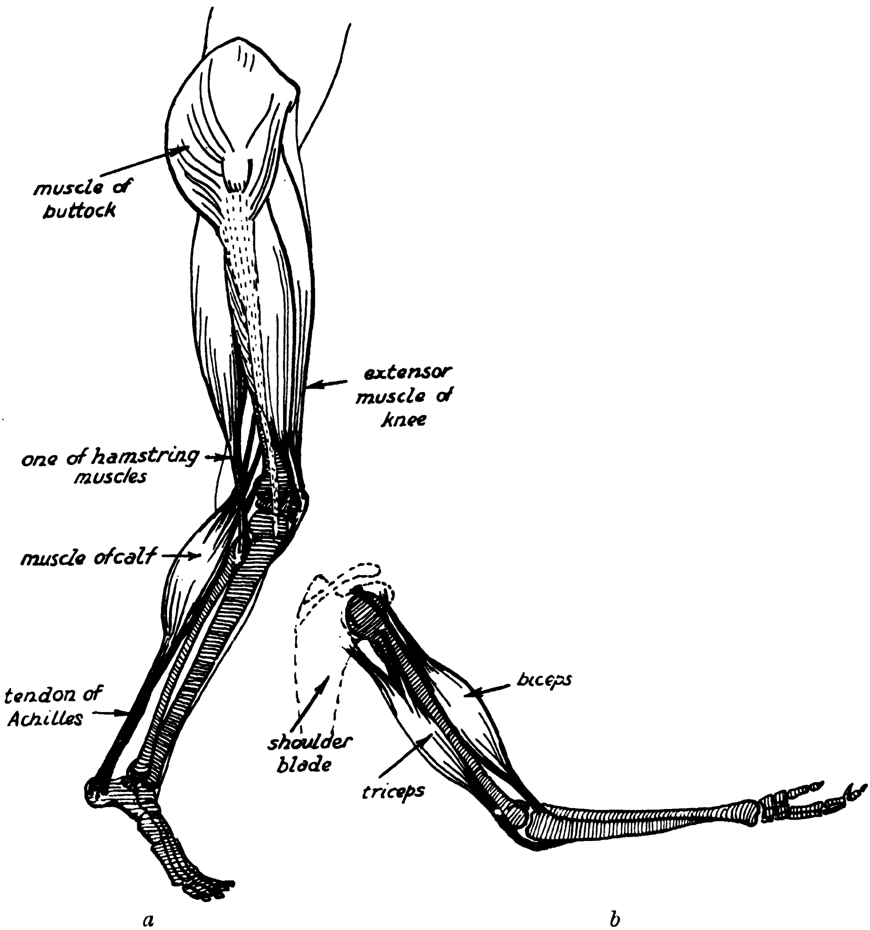


FIG. 241
Some muscles of the lower (left) and upper limb

any weight which it may contain, by means of force exerted on the bones of the lower arm. The fulcrum in this case is the upper end of the ulna. This lever works at a considerable mechanical disadvantage, as do many other bones which act as levers. No other state of affairs is possible in the compact body of an animal.

There are examples in the mammalian body of levers used in other ways. Thus, in lifting up the heel, the bones of the foot are used as a lever (Class II, p. 32) to hoist up the weight borne by the shinbone. In this case, the force is exerted by the muscles attached to the heel bone by the tendon of Achilles. The nodding movements of the skull on the atlas provide yet another example of the action of a lever (Class I, p. 31). The heavy front part of the head is jerked upwards by muscles at the back of the neck pulling on the other end of the lever, namely the skull itself.

Walking.—Most movements depend on the balance between various groups of muscles. Something like two hundred and seventy muscles are involved in various ways in walking in man, all being called into action at the appropriate moment by changes in balance. The muscles involved in walking are shown in Fig. 241*a*. As explained in the preceding paragraph, the muscles of the calf contract and raise the heel from the ground. The muscles controlling the movements of the knee are termed respectively the extending or extensor muscles on the anterior side of the leg, and the flexor or hamstring muscles on the posterior side. If the latter are cut, the knee cannot be bent. The movement of the leg as a whole is carried out by muscles, including those of the buttocks, which have their origin on the pelvis and their insertion on the femur. Some fifty muscles are involved in the movement of each leg. The control of such numbers of muscles is carried out by the nervous system, and has, in most cases, to be learned. The acquirement of skill in any game or in any other operation is largely a matter of the accurate timing of muscular movement. It is scarcely surprising that a child takes some time to learn to walk!

Types of Muscle.—The muscle described in this chapter is the voluntary or striated type. The type of fibre found in muscles which cannot be controlled by the will is very different. In this case, each fibre consists of a single spindle-shaped cell with a nucleus. A third type of muscle cell is found in the heart. In this case, the fibres each consist of a single cell, but they are striated and are sometimes branched. The heart muscle is, of course, in continuous action throughout life.

Other Types of Skeleton.—Some animals such as jelly-fish and worms have no skeleton at all. Snails and related animals have an unjointed shell into which the animal can retire when threatened.

The external skeleton of crabs, spiders, cockroaches and flies is a jointed suit of armour produced by the layer of living material immediately below it. This skeleton consists of a substance known as chitin, sometimes strengthened and made more bulky, as in crabs, by the addition of salts of lime. The skeleton is thus not a living tissue, as is bone. Such a skeleton has, however, a serious disadvantage in that it severely restricts growth, and involves a series of moults without which the animal would not be able to grow at all. When moulting takes place (Fig. 242) the skeleton splits and the animal withdraws, leaving behind a complete replica of itself. The skin now hardens into a new skeleton, but the animal is necessarily very defenceless during this period. In addition this type of skeleton is fairly easily damaged, with

Courtesy of D. P. Wilson, Marine Biological Lab., Plymouth

FIG. 242

Swimming Crab (Portunus depurator) casting its shell

disastrous results, for it is not readily repaired. There is the further point that this type of skeleton does not produce the complex joints which play such an important part in free movement. However, one has only to think of the extremely rapid

movements of flies to realize how efficient the external skeleton can be for small animals. The muscles are in this case inside the skeleton and the limbs are moved by the contraction of muscles in the usual way.

CHAPTER XXXVI

CO-ORDINATION AND BEHAVIOUR

MOST of our reactions to external conditions are carried out by muscles or glands. Examples of muscular movements are the withdrawal of the hand from contact with a very hot plate, blinking when the eye is threatened, coughing when crumbs of food enter the windpipe, and sneezing when the nasal membranes are irritated by foreign bodies. An example of the reaction of a gland is the secretion of saliva when food enters the mouth. In all these cases the effective external condition or stimulus is perceived by an organ of one of the five senses—sight, hearing, smelling, tasting and feeling. Muscles, glands, sense organs and all the other organs in the body are connected by nerves to the central nervous system, which consists of the brain and spinal cord (Fig. 243). In many ways the central nervous system resembles a very complicated telephone exchange receiving information from the sense organs and transmitting " instructions " to the other parts of the body. A unit of behaviour, such as any of those mentioned above, is termed a reflex and involves the participation of a sense organ, a nerve which conveys an impulse to the central nervous system, the central system itself, a nerve conveying an impulse outwards from the central system to the muscle or gland, and the muscle or gland itself. This circuit is known as the reflex arc (Fig. 244). Reflexes are largely automatic and are not consciously controlled. In some cases, however, as in the first of those mentioned above, the response may be modified by the will.

A Reflex in Detail : the Knee Jerk.—The knee jerk is an example of a reflex in which the nervous impulse travels to the spinal cord and not to the brain. If a man sits with one leg hanging over the other and smartly taps this leg just below the knee cap a sharp uncontrollable jerk is the result. It is used in medicine as a test to discover whether or not the nervous system is functioning properly. The blow indirectly stimulates the microscopic sense

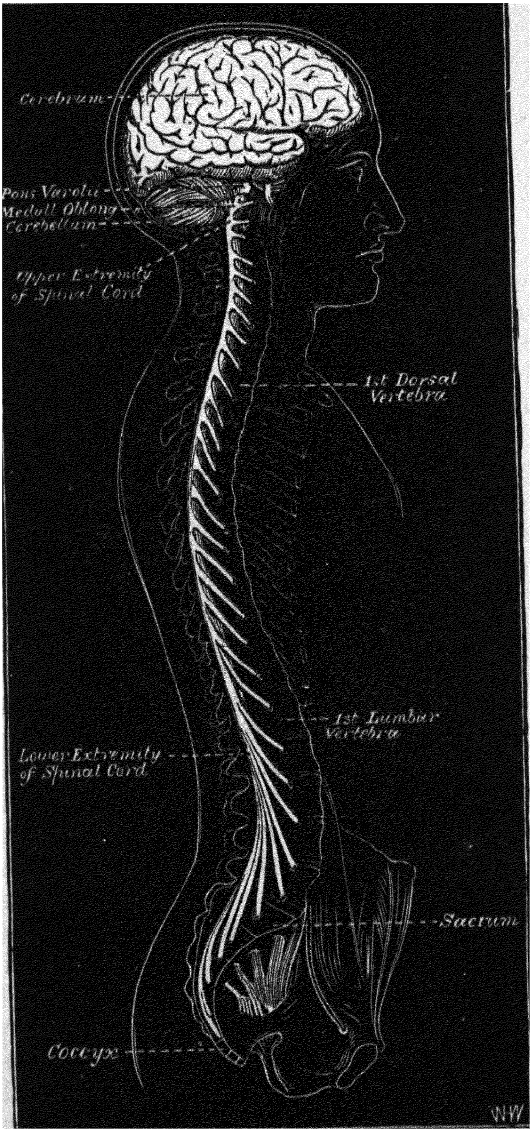


FIG. 243
The human nervous system

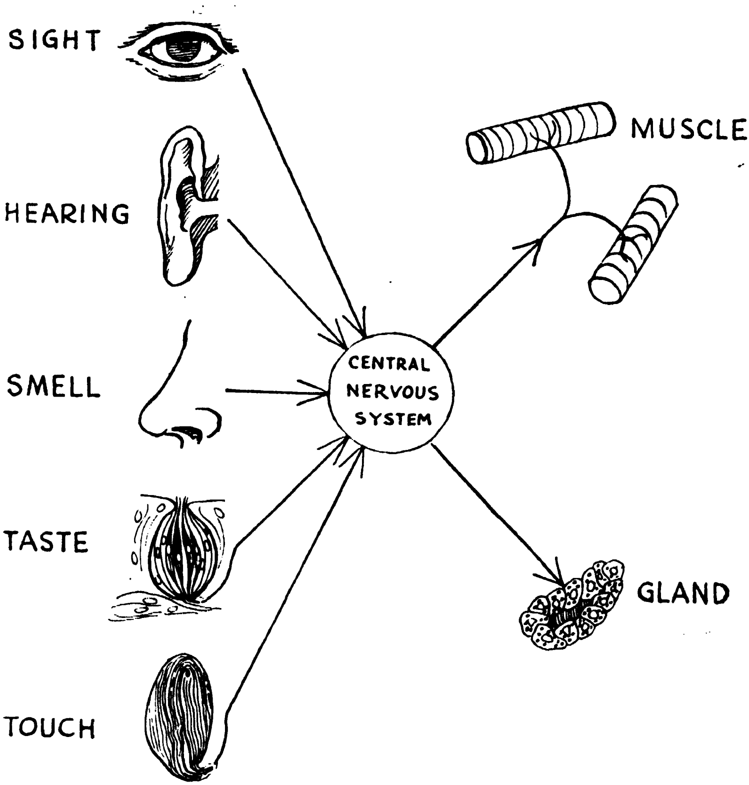


FIG. 244
Structures concerned in reflex actions

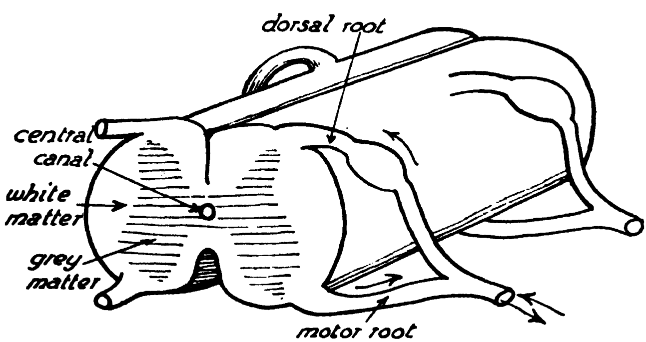


FIG. 245
Transverse section of spinal cord

organs in the extensor muscles of the knee, which are inserted on the shin bone. These sense organs are supplied by branches of the sciatic nerve and a nervous impulse passes along this nerve to the spinal cord.

The structure of the spinal cord is shown in Fig. 245. The grey matter consists of nerve cells, each of which has a nucleated central region with numerous branching processes radiating from it (Fig. 246). One of these processes, termed the axon, is very thin and very long, sometimes several feet in length. Nerves consist of

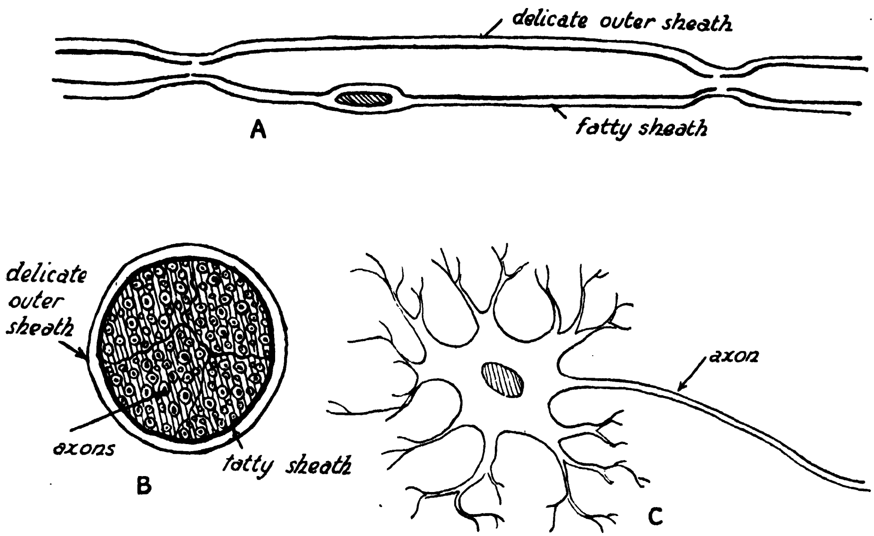


FIG. 246

A, longitudinal section of small nerve ; B, transverse section of small nerve ; C, single nerve cell

bundles of axons, surrounded by a sheath of fibrous tissue which contains a definite layer of fat. The other branching processes of a nerve cell come into intimate contact with similar processes from other nerve cells forming junctions termed synapses. When the incoming or sensory impulse arrives it passes into the grey matter, across many synapic junctions, and emerges along different axons as an outgoing, in this case a motor impulse. The sciatic nerve is the large nerve of the leg which is formed by the fusion of several spinal nerves. It may be seen in Fig. 245 that each nerve has two roots, of which the dorsal is the route taken by the incoming, the ventral that taken by the outgoing impulse. The swelling

on the dorsal root contains nerve cells in communication with those of the grey matter of the spinal cord. In the case of the knee jerk, the outgoing impulse is conveyed to the extensor muscles of the thigh, which respond by contraction.

The Nervous Impulse.—The impulse passing along a nerve is accompanied by an electric current to which the impulse is in many ways similar. The impulse is not so rapid as an electric current, but nevertheless travels very quickly at a speed which depends upon the temperature. In man, nervous impulses travel at approximately four hundred feet per second at body temperature. The speed in the sciatic nerve of a frog at room temperature is barely a quarter of this figure. It is possible to induce contraction in a muscle by passing an electric current along the nerve which supplies it. A suitable subject for this experiment is the large calf muscle of the frog and the sciatic nerve which supplies it. The nerve is cut near the pelvis and the tendon at the ankle and the two structures removed from a freshly killed animal. If this preparation is bathed with a solution of salts of a similar concentration to that of the blood, the muscle and nerve can be kept alive for some little time. When the nerve is stimulated by a current the muscle immediately contracts and the contraction may be recorded on a revolving drum by means of a pointer.

The Sense Organs.—The eye functions in much the same way as a camera (p. 112). The eyeball itself (Fig. 247) consists of three layers enclosing a cavity filled with fluid, the whole structure being pulled into various positions by six muscles at the back of it. The outside layer must be impermeable to light rays, as in a camera, though the front part of it, called the cornea, is transparent. The cornea allows the light to enter and the aperture of this "camera" is determined by the middle layer of the eye, which forms a coloured curtain called the iris just in front of the lens. This curtain is muscular, and when it contracts, the pupil, which is the space in the centre of it, enlarges and more light can enter. The rays of light entering through the cornea are focused by the lens on to the sensitive internal layer of the eyeball, called the retina. Nerve impulses set up in the retina are conveyed by the optic nerve to the brain. The focal length of the lens can be changed by the ciliary muscle, which is capable of contraction, thus altering the curvature of the lens. We can, in this way, accommodate our eyes to see objects at varying distances. The spaces

in front of and behind the lens are full of fluid. The image formed on the retina is actually inverted, but is corrected by the brain. When the image is indistinct, it is often due to the fact that the eyeball is relatively too short or too long for the image to be correctly focussed (p. 113).

The ear is a complicated piece of apparatus which consists of several parts (Fig. 248). The most important part of all is the inner ear, consisting of a membranous structure full of fluid, well protected by certain bones on the lower side of the skull. This is connected to the brain by the auditory nerve. The function

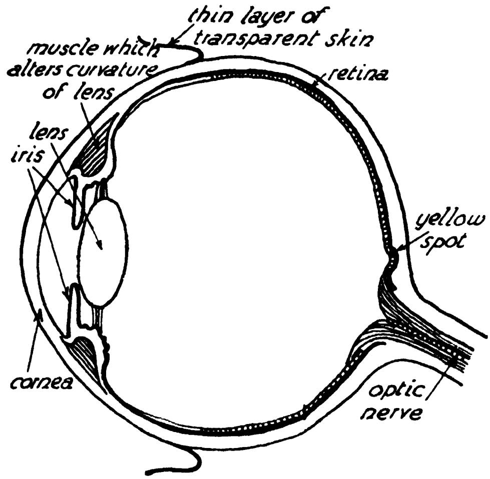


FIG. 247
Longitudinal section of the eye

of the outer ear is to collect sound waves which set the very delicate ear-drum at its base vibrating. These vibrations are carried across the middle ear by means of three bones which form a chain across it. These bones are called, from their shape, the hammer, the anvil and the stirrup. In order to ensure that the pressure on both sides of the ear-drum shall be constant, the middle ear is connected by a tube to the back of the mouth. The three bones are set vibrating by the movements of the ear-drum, and in this way the sound waves ultimately set up in the fluid inside the inner ear movements which stimulate sensory cells. As a result, nervous impulses are conducted to the brain by a sensory nerve. The ear is also concerned with the sense of balance. One part of the internal

ear carries three semicircular canals, two vertical at right angles to one another, the third horizontal, one end of each canal being rather swollen. The canals contain fluid, and the sense of balance is due to the movements of this fluid over certain sensory cells in the swollen ends. Giddiness is an obvious result of the swirling movements of the fluid after any rotating movement.

The sensory cells which are responsible for the sense of smell

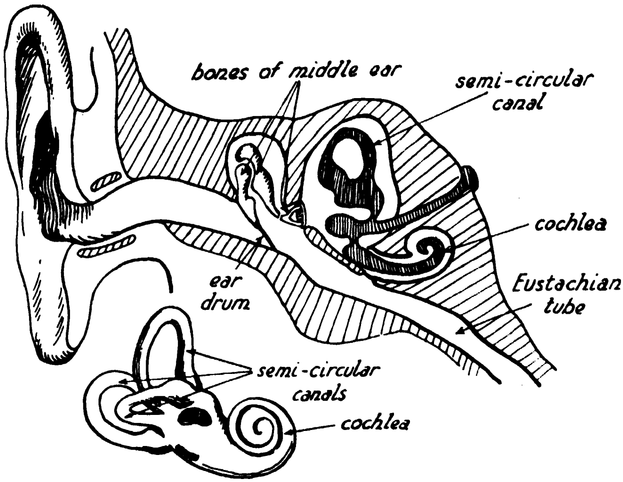


FIG. 248
The ear

are scattered in the membrane lining the nasal passages; those for taste on various parts of the internal lining of the mouth, particularly on the tongue (Fig. 244). They are capable of distinguishing between four different tastes—sweet, bitter, acid and salt. In the skin are small organs, some similar to that shown in Fig. 244, which are connected by nerves to the central nervous system. These are responsible for the sense of touch and are particularly abundant on the under side of the foot and on the palm of the hand.

The Brain.—The brain consists essentially of the same kinds of material as the spinal cord—grey and white matter. The chief difference is the much greater complexity of the brain and the fact that the grey matter is largely superficial. In the brain of the dogfish the lobes connected with the smelling organs are very large, and are connected to the cerebrum in the centre. Just behind the latter are the optic lobes, which are connected with

the eyes. The large structure immediately behind these lobes is the cerebellum, which controls the condition of the muscles and also regulates their movements. The hind part of the brain is the medulla oblongata which adjoins the spinal cord and is concerned chiefly with reflex actions.

The mammalian brain (Fig. 249) is completely different in shape and is relatively very much larger. The lobes connected with smelling are very small and lie on the under side of the enormous cerebral hemispheres, which form the great bulk of the brain. These have developed from a special part of the cerebrum, barely

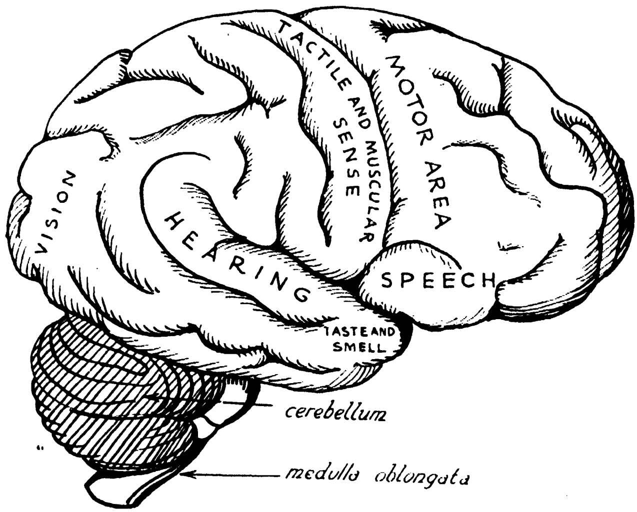


FIG. 249

Side view of the human brain

represented in the dogfish. In the dogfish there is little connexion between the parts of the brain responsible for different functions. In the mammalian cerebral hemispheres there are many co-ordinating centres. The grey matter is here superficial, and certain areas of the hemispheres have been shown to be connected with special functions, such as movement, vision, hearing and speech, but these areas do not by any means represent the whole. There is no doubt but that memory and learning, which have played such a large part in the success of mammals, are connected with the cerebral hemispheres. The latter structures are relatively

larger still in man, a fact which confirms the above conclusion. The other parts of the brain have much the same functions as in the dogfish.

Co-ordination by Hormones.—The nervous system provides the mechanism of co-ordination of actions which are performed quickly. There is, however, a system of chemical control over many activities in which speed is not so essential. Reference has been made in previous chapters to the hormones insulin and secretin, produced by the pancreas and the duodenal wall respectively. Many other hormones are produced by other organs, notably by several ductless glands, the products of which pass into the blood. The most important are the adrenal glands (one near each kidney), the thyroid gland (just below the larynx), and the pituitary gland (attached to the under side of the brain and fitting into a little socket on the floor of the skull).

The secretion of the hormone adrenalin by the adrenal glands is greatly speeded up by any kind of excitement. The effects produced by the hormone, a selection of which are a rise in blood pressure, an increased supply of blood to the muscles, hair standing on end, and slowing down of the digestive processes, are of such a nature that it is thought that the function of the hormone is preparation for an emergency. Thyroxine, produced by the thyroid gland, stimulates the chemical changes which take place in the body. It is essential for the growth of the tadpole into a frog and is, in fact, essential for the development of young vertebrate animals. The pituitary is a highly complicated gland, producing hormones which, among other things, co-ordinate the growth of bones, stimulate metabolism, and, together with the hormones produced by the reproductive organs, control many reproductive phenomena. It is probable that nerve endings, when stimulated by an impulse, produce a hormone, which brings about the actual changes concerned.

Hormones are, then, of the greatest importance. It sometimes happens that the gland concerned produces an inadequate supply of hormone, or is too large and produces too great a quantity. Thus sugar diabetes (p. 276) is due to the absence of insulin, and various disorders, including cretinism and goitre (p. 383), are due to derangements of the thyroid. Theoretically many such diseases can be cured by administering to the patient the correct quantity of the appropriate hormone prepared from an animal, or by surgical removal of part or the whole of the gland.

Behaviour of Animals.—When the movements of the microscopic animal Paramecium (p. 367) are examined under the microscope it is discovered that it has one reaction and one only to unfavourable external stimuli. If, for instance, it comes into contact with a small drop of oil placed in the water it reverses, points in a slightly different direction and moves forward once again. This reaction is one of unconscious trial and error, and is an example of very primitive behaviour.

Blow-fly maggots enclosed in a blackened rectangular box, which is illuminated from one side only, will move rapidly in the opposite direction. If illuminated from two adjacent sides the maggots will move away from the two lights along a line midway between them. A blind unconscious reaction of the whole body such as this is known as a tropism and is a direct result of the action of the stimulus on the nervous system. Strictly speaking the term taxis should be used for a reaction of the whole body, and the term tropism for a reaction of a part of the body. The term tropism is, however, frequently used in both of the above senses. Usually the response is useful to the organism ; but in some cases, as when a moth flies into a flame, the response is exactly the opposite. Tropisms and reflexes are largely responsible for the very intricate instincts of many insects, such as those of ants and bees, and are thus responses to various internal and external stimuli, and do not have to be learned.

Tropisms are characteristic of comparatively simple organisms. The behaviour of the dogfish, which possesses a brain in which there is little connexion between the centres responsible for various activities, is largely a matter of reflexes. In the higher vertebrates, reflexes become more complicated in that the response tends to be made not only to the stimulus but to other conditions associated with the original stimulus. Thus when a dog is fed at the same time every day and a bell is rung at the same time, the dog will soon begin to secrete saliva when the bell is rung whether the food is there or not. Some of our own behaviour is made up of these so-called conditioned reflexes. The very large number of nerve cells in the mammalian brain makes possible a great variety of response to stimuli in a way which is impossible in insects which have a comparatively small brain with relatively few nerve cells. The intelligent behaviour of the mammals and of man goes hand in hand with the increasing number of nerve cells in the cerebral hemispheres which make learning and memory possible.

CHAPTER XXXVII

INSECTS

THE first insect to be described is the cockroach because it has the great advantage of being sufficiently large for all the important structures to be seen, and also because it is not specialized to any particular kind of life. Four species are native to this country, but the two species most commonly encountered here are native to North America and Asia respectively. The former is the larger and lighter in colour, and both sexes have long wings, the front pair being modified into horny wing-cases. In

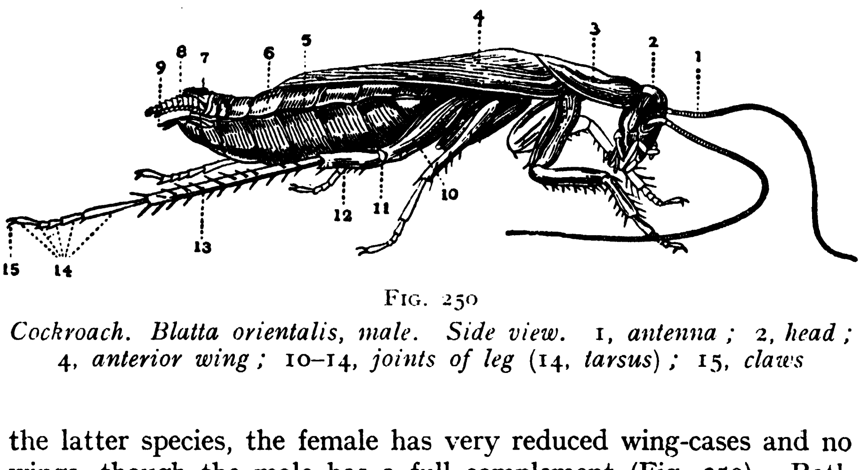


FIG. 250

Cockroach. Blatta orientalis, male. Side view. 1, *antenna*; 2, *head*; 4, *anterior wing*; 10–14, *joints of leg* (14, *tarsus*); 15, *claws*

the latter species, the female has very reduced wing-cases and no wings, though the male has a full complement (Fig. 250). Both kinds are common nocturnal pests in kitchens and buildings generally. They are omnivorous and eat any kind of food which is available.

Insects are segmented, though they have a much smaller number of segments than worms. They are characterized by the grouping of the segments into a head of six, a thorax of three and an abdomen of eleven segments. These segments are all visible externally

except in the head, where they have all become fused together, and in the hinder part of the abdomen, where they are telescoped.

Some of the twenty segments of the insect each possess a pair of limb-like structures, which are used for many different purposes. In the head there are four pairs of these appendages, the antennæ or feelers, which bear sensory hairs for feeling and smelling, and three other pairs collectively known as the mouth parts (Fig. 251). The front pair of these three, which belong to the fourth segment, has been modified into a pair of powerful jaws, or mandibles, which bite from side to side. Hanging down behind these is a pair of subsidiary jaws, the maxillæ, which help to cut and tear up the

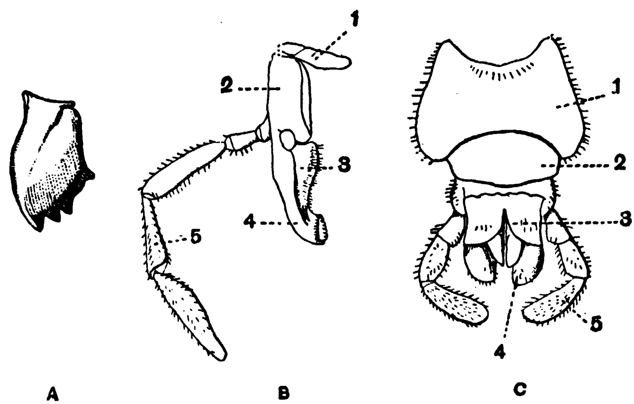


FIG. 251

Mouth parts of Blatta orientalis. A. Mandible. B. Maxilla. 3, 4, *subsidiary jaws.* 5, *palp. C. Labium.* 4, *subsidiary jaw.* 5, *palp.*

food and to push the pieces between the mandibles. The maxillæ also bear structures known as palps, which bear sensory hairs for tasting and feeling. Behind the maxillæ hangs the labium, consisting of two appendages fused together. Each of the latter is not unlike a maxilla, consisting of subsidiary jaws and a palp. In many insects the mouth parts have been considerably modified for other purposes, such as piercing and sucking. Each of the thoracic segments bears a pair of jointed legs. The two pairs of wings, when present, are also borne on the thorax, one pair on each of the two posterior segments. The veins, which are characteristic of membranous insect wings, are thicker parts of the wing enclosing air tubes or tracheæ. The possession of the following characteristics is sufficient diagnosis of an insect: segmented external skeleton,

head of six segments with one pair of antennæ and three pairs of mouth parts, thorax of three segments with three pairs of legs and two pairs of wings (when present) and an abdomen of eleven segments or less with no obvious appendages at all.

The life history of the cockroach is very simple. The female deposits sixteen eggs enclosed in a chitinous structure which she manufactures. This is extruded from the body as a cocoon, and eventually the young animals emerge. They are complete in every detail except that they have no wings. They begin to feed in the same way as the adults, and within a week or so have grown to such an extent that the pressure on the external skeleton becomes too great. The skeleton then splits along the middle of the back, the insect picks itself out, and the cuticle hardens to form a new skeleton. This process of moulting is made possible by the pouring out of a lubricating fluid, and takes place six times in all before the cockroach becomes mature in about six months. At each moult the wings become larger, finally arriving at their full size at the last moult.

Butterflies.—Butterflies are much more specialized insects than cockroaches. The body of the adult or imago is much more delicate and the mode of life is very different. The two pairs of wings are very large and are covered by very numerous small pigmented scales, which make up very striking patterns. It is noteworthy that the white colour in the scales of the cabbage white is due to uric acid—a waste product containing nitrogen. Butterflies sip up the nectar from flowers, and for this purpose they have a long tube or proboscis which, when not in use, is coiled up underneath the head (Fig. 252). The tube is formed of two halves loosely joined together, each half corresponding to part of the maxilla of the cockroach.

The life history involves no less than four distinct stages (Fig. 252). There are two broods of the cabbage white, one from eggs laid in the autumn, the other from eggs laid in the spring. The eggs are beautifully sculptured conical structures, from which the larvæ (caterpillars) soon emerge. They have a very hearty appetite, and use their mandibles to eat cabbage leaves until they can literally eat no more. During this period, which lasts for several weeks, the caterpillar, which has only a thin cuticle, moults several times. The head of the larva is clearly marked, but the thoracic and abdominal segments all look alike except for the difference in the appendages which they bear. The true legs of the larva are fat jointed structures, each ending in a claw, while on abdominal

segments 3–6 are prolegs, shorter and fatter than those on the thorax, each bearing a circlet of hooks.

When it has finished feeding, the larva begins to climb up a fence or some similar structure where it is likely to remain undisturbed. As it does so, the head is turned backwards, and a fine stream of silk is poured out of the spinneret, an organ which corresponds to the labium of the cockroach. The shape now changes a great deal, the front end expanding a good deal and the body becoming relatively shorter. Several chitinous spines are formed, and the

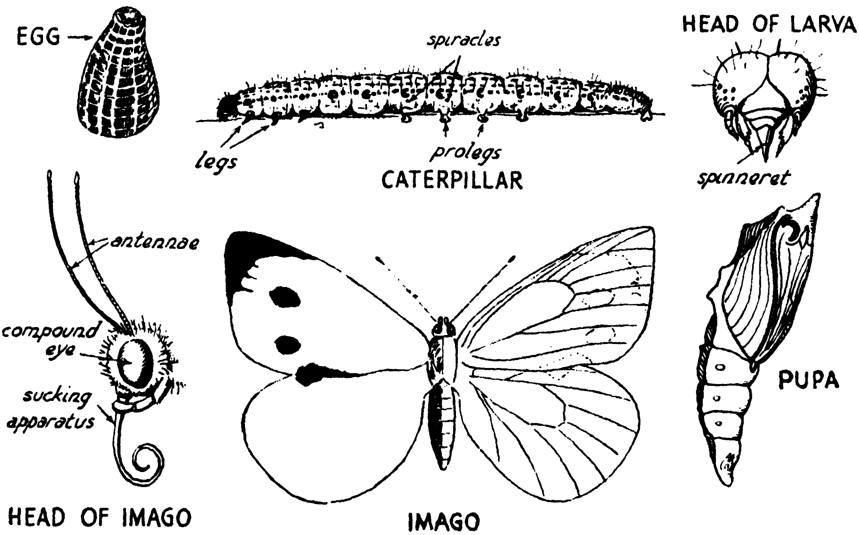


FIG. 252
Life history of cabbage white butterfly

colour becomes a brownish yellow. This stage is known as the chrysalis or pupa ; it remains absolutely quiescent for several weeks in the case of the spring brood of butterflies, for the whole winter in the case of the autumn brood. Finally, it moults for the last time, the imago withdraws from the pupal skin and when the wings have expanded and dried, flies away. The chrysalis does not feed at all, and undergoes vast internal reconstruction during this period. More will be said about the significance of this process in due course (p. 345).

Mosquitoes.—Mosquitoes and gnats are more or less synonymous names for certain common flies. The following description will apply equally well to the common gnat or to the mosquito

commonly found in houses. The chief distinguishing feature of flies is that they have no second pair of wings, though these are represented by a pair of small sensory organs on the last thoracic segment. The mouth parts of the mosquito are modified for piercing and sucking (Fig. 253). The mandibles and maxillæ have here become long piercing structures, contained in a long projecting trough which represents the labium. The trough is closed at the top by a tube formed of two pointed structures, outgrowths of the roof and floor of the mouth respectively. The lower one carries the salivary duct, through which a fluid is injected into the wound which the lancets have made. This fluid stops the blood from clotting, and in some mosquitoes, contains the minute organisms responsible for malaria (p. 386). The blood is sucked up through the tube formed by the two outgrowths.

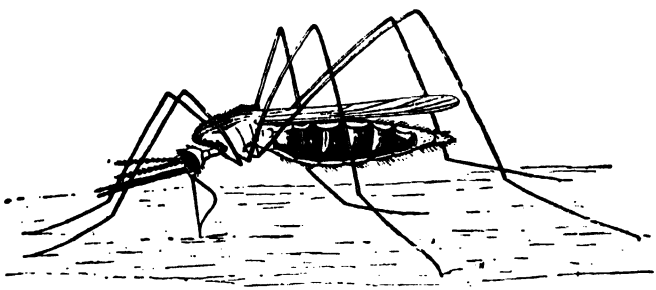


FIG. 253
Mosquito in the act of biting

The life history is made up of the same four stages as in the butterfly (Fig. 254). The eggs are laid in water and, in the common species Culex pipiens, form a raft in which the eggs are so closely packed that water cannot enter between them. Each is heavier at its lower end. The larvæ which escape from the lower end of the egg cases are characterized by a largish head bearing fringed organs, which by their movements create a current bringing small particles of food into the mouth. There are no appendages on the thorax. From the last segment but one of the abdomen projects a tube which has a lobed apex. These lobes project above the surface film of the water and the larva is thus suspended head downwards. The tube contains two large tracheæ which pass longitudinally through the body. Thus the larva, though living in water, breathes by means of tracheæ, and obtains its oxygen

direct from the atmosphere. The larva frequently darts downwards from the surface by means of wriggling movements of the abdomen, which terminates in a number of swimming plates. The

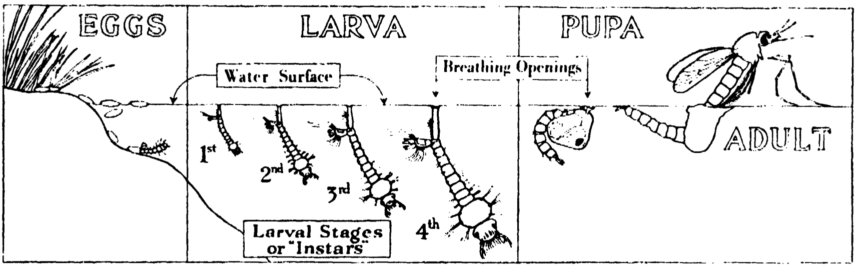


FIG. 254

Life history of a common mosquito which does not form an egg raft

head and thorax of the pupa form a large rounded mass, which bears a pair of respiratory tubes. The pupa, unlike that of the butterfly, can, if disturbed, move about vigorously by movements of its abdomen, which terminates in three swimming plates.

The House-fly.—The house-fly is also a true fly, and has mouth parts which resemble in some ways those of the mosquito. The piercing organs of the mosquito have disappeared completely, but the two lobes termed labellæ at the end of the labium have been modified for sucking. Liquids are sucked up by capillarity into the channels on the under side of the labellæ and into the tube formed by the outgrowths from the roof and floor of the mouth. In the case of soluble food, such as sugar, the fly emits from the front part of its intestine enzymes which dissolve these substances and the fluid so formed is sucked into the mouth as before. It is thus possible for house-flies to distribute bacteria contained in any of their food over a wide area, and their presence should not be encouraged. Bacteria may also be entangled on the legs of flies (Fig. 276).

The eggs are laid in rubbish of various kinds, those of the blow-fly in meat. The larvæ (Fig. 255) which hatch from the eggs have a very pointed anterior end and are legless. They breathe through large spiracles at the anterior and posterior ends. When young, they are greatly affected by light, and wriggle rapidly, in spite of the absence of legs, in the opposite direction when light is directed on to them. These larvæ are apparently headless, but the head is actually tucked away inside—inside out. The pupa is covered

by a brown structure called the puparium, which is actually the last larval skin. When the fly is ready to emerge, the front end of it is knocked off by the expansion of a special organ on the head of the fly—the ptilinum.

It has been shown that, in these flies, the internal reconstruction in the pupal period reaches its maximum. In addition to the fact that the head turns inside out, all the organs are broken down

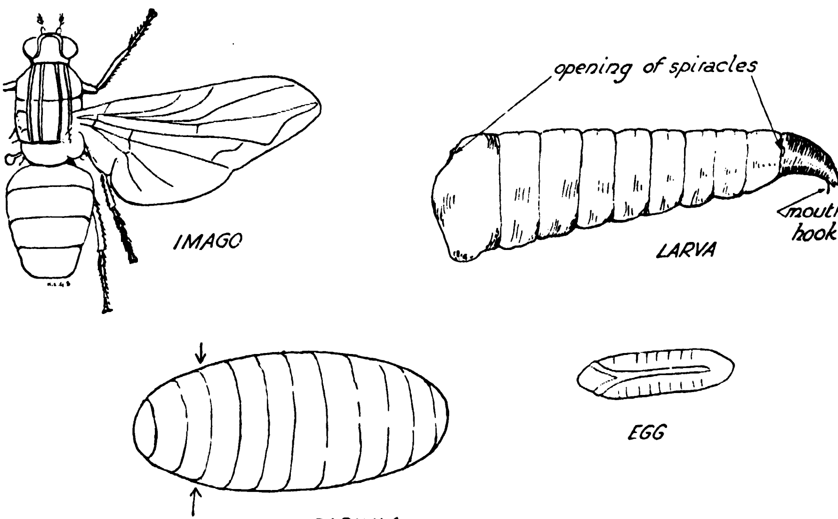


FIG. 255
Life history of house-fly

and built up again, except the heart, the reproductive organs and the nervous system. There has been much discussion of the significance of the pupal stage of insects. It is suggested that the larvæ of insects are so suited to a particular mode of life that the larval organs are quite useless for the adult, which leads a completely different kind of life. Hence the need for a radical reconstruction.

The Hive-bee.—Some insects, such as the hive-bee, ants and wasps, live in large communities in which a very high type of communal life is found. The example to be described is the hive-bee. The hive-bee collects a sugary fluid, nectar, from flowers, and from it produces honey. Nectar is collected by the mouth parts, which are much modified for sucking. The mandibles are

small and used only for manipulating wax. The "tongue," by means of which the nectar is gathered, corresponds to part of the labium. The nectar is sucked into the crop or honey stomach in the abdomen, where the saliva acts upon it, changing the cane sugar of the nectar into simple sugars, including grape sugar. The product is regurgitated as honey when the occasion arises. Bees collect nectar from many flowers, including Dutch clover, lime and heather. They can also make use of the juices of ripe fruit. On any one journey, the bee will keep to one kind of flower, which is recognized by its colour and shape.

Hive-bees also collect pollen from flowers by means of the legs, which are specially modified for the purpose. On the fourth joint

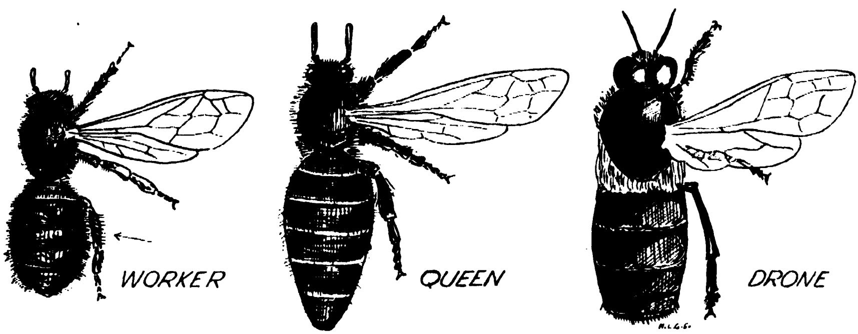


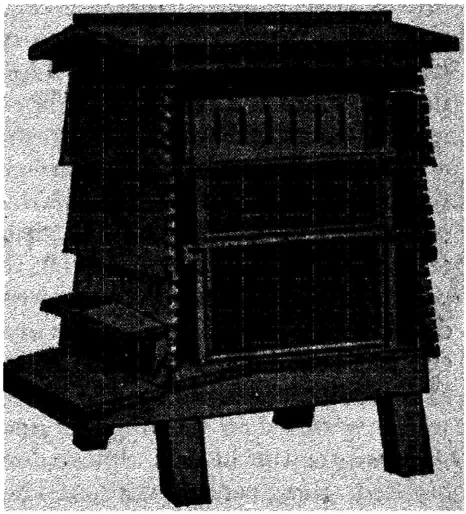
FIG. 256
The hive-bee—worker, queen and drone

of the hind legs is a depression fringed with bristles, which is called the pollen basket. The first joint of the tarsus (Fig. 250) is enlarged and carries a brush of hairs, which is used for brushing pollen collected by the hairs of the body into the basket on the opposite leg. In addition, the middle legs bear a prong which is used for digging out the pollen from the basket.

The individuals which carry out these functions are termed workers, and are responsible for all the activities of the hive except that of laying eggs. They are females which have not become fertile, only a few individuals becoming fully fertile queens (Fig. 256). It has been shown that the queens develop from larvæ which have been fed on special food, which is called the royal jelly. There is a third type of individual in the hive, namely the drones, which, as their name implies, have practically nothing to do.

Actually the drones are the males, but only a very few of them function as such.

A hive is a complex structure, designed to give the bees as much assistance as possible in carrying out all their activities, and for removing the honey which they produce. The section of a hive shown in Fig. 257 gives a good idea of its structure and contents. The structures inside the hive are called frames, their purpose being the support of the cells formed by the bees. Each frame has a wooden skeleton and the interior is further supported by wire. Sheets of foundation wax are introduced so that the bees can begin to form cells immediately. The frames are of three different kinds: at the base is the brood chamber, consisting of several large frames arranged in such a way that there is adequate aeration as well as sufficient heat for the survival of the brood. The queen is confined to this region of the hive by a "queen excluder," which is a perforated zinc plate. The holes in the plate are large enough to allow workers but too small to allow queens to pass through them. Above this is a box of shallow frames, used for extracted honey, while above these is the section rack with twenty-one sections, which average a pound in weight when full of honey.



Courtesy of E. H. Taylor, Ltd., Welwyn, Herts

FIG. 257

A modern beehive

It is convenient to begin the history of a new hive with a swarm which issues from one of the old hives. The reason for its emergence is gross overcrowding, the old queen and several thousand workers settling on a tree or some suitable object, the workers clustered round the queen in a motionless mass. The swarm is removed, and introduced either through the top or the entrance of the hive towards the evening. At first only the frames of the brood chamber are left in the hive, and a supply of sugar solution is advisable. The bees then begin to construct the six-sided cells on the frames,

sometimes as many as four thousand cells in twenty-four hours. The wax for this purpose is secreted by the glands on the abdomen, the scales in which it appears being removed and worked into a soft mass by the mandibles. The workers also use a substance termed propolis as a kind of glue. It is gathered from sticky material from trees.

As soon as the cells are ready, an egg is laid in each one by the queen. In spite of being unfertilized (p. 391), these eggs produce the workers of the next generation. In about three days a tiny legless grub emerges from the egg, and is carefully tended by the workers. The rich food supplied to the grubs is a product of some glands in the mouth cavity. The food is later changed to "bee-bread," which is a soft paste of honey and pollen. The grub moults several times and when full grown is sealed by a porous lid, spins a silken cocoon and becomes a pupa. After a week it bites its way through the cocoon and begins to work. For the first fortnight of its life, the worker helps to clean and ventilate the hive and to tend and feed the larvæ. After this period it collects nectar and pollen until it dies some six weeks later. The total period of development of the worker is twenty-one days from the time the egg was laid. Their numbers increase greatly during the summer, and provision is made for the winter by the manufacture of honey, which is stored in the upper frames in the hive.

In winter the hive is almost dormant. Since the bees are cold blooded, they cannot stir outside, and there would be no food material to gather if they did. The heat produced by the metabolism of the enormous numbers of bees inside the hive make the continued existence of the community possible. The workers gather in a mass about the queen, and there is a stock of honey sufficient for all their needs.

As early as February, the queen begins to lay more eggs, and the population problem becomes really serious. Before the old queen leaves the hive with the first swarm, special provision is made for new queens and drones. A few hundred drone cells are constructed and an egg deposited in each. Only a few royal cells are made, and eggs laid in each at intervals of some thirty hours. The grubs hatching from the latter are supplied throughout with "royal jelly," which is identical with the food supplied to the grubs of the workers and drones for the first three days. The complete development of the new queen, the first of this batch to emerge, occupies sixteen days, and her first action on emergence

is to sting and kill the pupæ in the remaining royal cells. If the first of the batch dies, the next becomes the new queen. The drones take twenty-four days to develop, their diet being much the same as that of the workers. They are larger and more powerful than the queens and workers, and follow the new queen as she emerges by herself one morning from the hive. She flies very high into the air, and ultimately only one of the males is able to reach her in order to mate. The drone dies, but the queen returns to the hive and begins to lay eggs very rapidly. On the approach of winter, the drones, which now serve no useful purpose, are slaughtered by the workers, and their bodies thrown out of the hive. It has been established that the spermatozoa (p. 392) passed into the queen's body by the drone are stored up and used to fertilize *some* only of the eggs which are laid. The unfertilized eggs become the drones, the fertilized the workers and queens.

The Economic Importance of Insects.—There are more kinds of insects than of all other animals. Many of them are exceedingly destructive to crops, timber, and animals, and are responsible for losses amounting to millions of pounds every year. Familiar examples of destructive insects in this country are wireworms, leather jackets, green-fly, caterpillars of various kinds, and weevils. Few plants remain free from the ravages of one insect or another for very long. Many insects such as cockroaches, earwigs, house flies, mosquitoes and clothes moths are in various ways household pests. Many biting insects, such as mosquitoes, tsetse-flies, lice and fleas, transmit diseases of various kinds. The death-watch and other beetles often play havoc with timber. On the other hand, many insects are useful because they feed on injurious insects. For instance, the lady-bird feeds on green-fly. Ichneumon flies lay their eggs in caterpillars: when the larvæ emerge they feed on the tissues of the caterpillar and kill it. It is sometimes possible to destroy insect pests by the introduction of another insect which feeds on the adult or larvæ of the pest. The products of some insects, such as the silkworm, are widely used by man. On the credit side, too, must not be forgotten the enormous importance of insects in bringing about pollination in plants (Chapter XXXVIII).

CHAPTER XXXVIII

FLOWERS

A FLOWER is a modified branch in which the swollen terminal portion (receptacle) bears the modified leaves which comprise the remainder of the flower. In the buttercup flower there are four kinds of modified leaves (Fig. 258). The function of the five

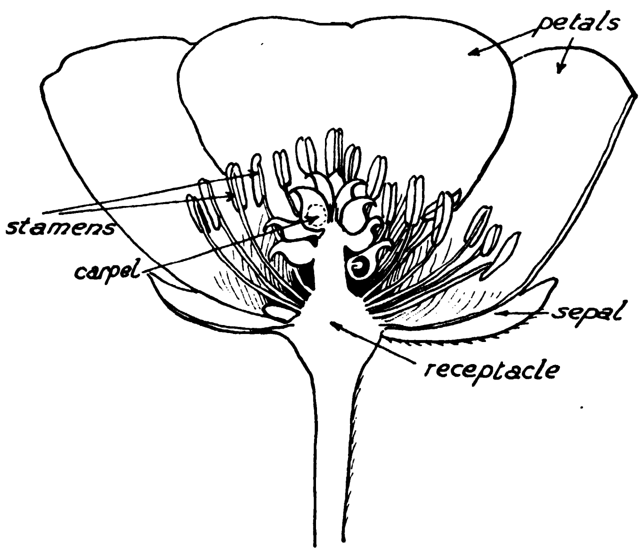


FIG. 258
Longitudinal section of buttercup flower

green or yellow sepals is to protect the flower while it is still in the bud. The five yellow petals are very conspicuous, and serve to attract insects to the flower. The most important leaves of the flower are, however, those modified into the numerous yellow stamens and the numerous green carpels. The structure of a stamen is shown in Fig. 259. It contains four longitudinal pollen

sacs which split when they are ripe, liberating a large number of microscopic pollen grains. Each carpel is a modified leaf containing in this case one ovule, which will in due course become a seed.

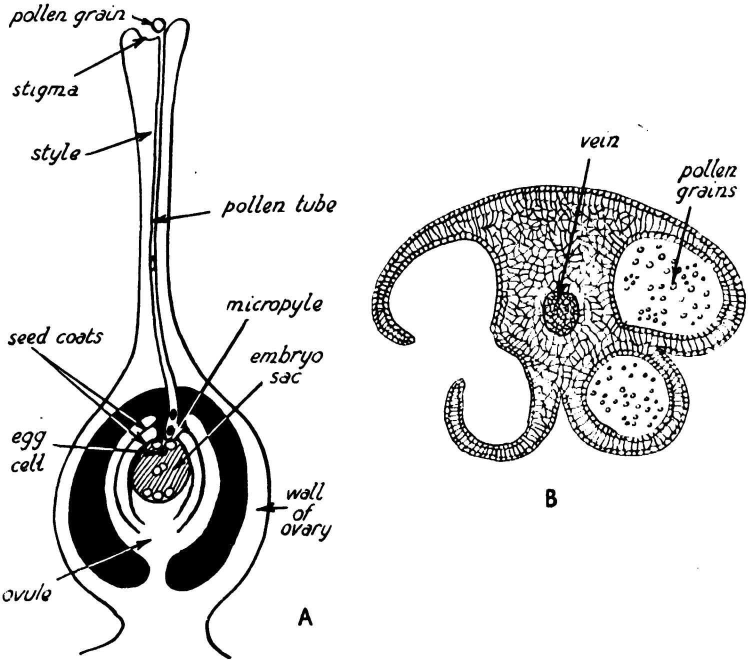


FIG. 259

A. Longitudinal section of ovary and ovule (generalized diagram). B. Transverse section of stamen

Pollination.—Nectar is produced by a small nectary on the inner side of the base of each petal. The nectar is sought by flies and bees which in gathering it become dusted with pollen. When the insect visits another buttercup flower some of the pollen becomes detached, and comes into contact with a receptive region at the tip of each carpel, which is known as the stigma. The transport of pollen and its subsequent deposition on the stigma of the same or of another flower is called pollination. In some plants it is brought about incidentally by insects in search of nectar or pollen, in others by the wind. The carpels of a flower are not usually ripe until considerably later than the stamens, and there is thus no danger of the pollen being deposited on the mature stigmas of the same flower. Thus cross-pollination is the rule, though self-

pollination is quite common. The buttercup flower is not sufficiently specialized in this connexion to rule out the possibility of self-pollination.

The structure of an ovule, somewhat simplified, is shown in Fig. 259. In the buttercup the ovule curves in such a way that the micropyle faces the stalk of the ovule. Just below the micropyle is the embryo sac, which, when mature, contains eight nuclei arranged as in the diagram. The innermost nucleus of the three just below the micropyle is termed the egg or female nucleus.

Fertilization.—The stigma produces a sugary solution which stimulates each pollen grain to send out a long tube which grows down the region known as the style, carrying two male nuclei at its tip. The tip of the pollen tube grows through the micropyle and one of the nuclei fuses with the egg nucleus. This fusion between a male and a female nucleus is termed fertilization, and must be carefully distinguished from pollination, which is merely the deposition of pollen on the stigma. In the pine there is an interval of a year between the two processes. The product of fertilization grows by stages into a tiny plant termed the embryo. The other nucleus of the pollen tube fuses with the two fused nuclei in the centre of the embryo sac. The combined structure grows into a tissue known as the endosperm, which supplies the growing embryo with food. After fertilization the ovule is known as a seed, and the carpel or ovary, as it is termed, is known as the fruit. The buttercup thus has numerous fruits, each containing one seed.

Pollen grains are very responsive to sugar solution, and the growth of the pollen tubes from them can be watched under the microscope. The pollen grains of Tradescantia, if in the right stage, begin to grow within about ten minutes of being put into a 1 per cent. solution of cane sugar. The usual procedure in this case is the "hanging drop method." A slide is employed which has either a sunken area in the middle or an artificial sunken area made by a wax or glass ring. A drop of the sugar solution is put on to a cover slip, a few pollen grains shaken into it, and the cover slip inverted over the sunken area, so that the drop hangs free from interference and free from the danger of drying up.

Specialization of Flowers.—Most flowers are considerably more specialized than that of the buttercup. Many are irregular, in that it is only possible to divide them into two symmetrical halves in one plane, a device to attract particular kinds of insects.

The petals frequently fuse into a tube, at the bottom of which is the nectar. In this way pollination is rendered more likely as the flowers are more distinctive and the insect returns to this type of flower as it has discovered an ample supply of nectar there. Thus, the number of stamens is reduced as less pollen is necessary, while the policy of producing a large number of carpels, each with one seed, is abandoned for that of a reduced number of carpels united with one another to form a large ovary, which produces a comparatively large number of seeds.

This change also involves a considerable change in the type of fruit. In the buttercup, each carpel ripens into a fruit containing one seed. Such a fruit, which, incidentally, does not split to liberate its seed, is termed an achene. When a reduced number of carpels fuse together to form a compound ovary, the latter ripens into a hollow structure termed a capsule which may split either down the lines of junction of the original carpels, or down lines representing the middle portion of each carpel.

The Lupin.—The lupin has become definitely adapted for

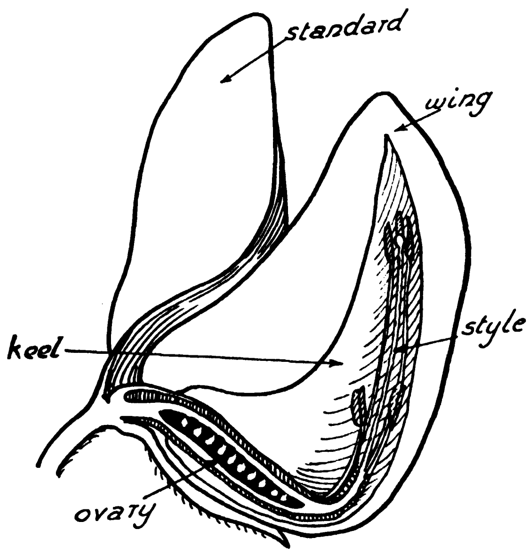


FIG. 260
Longitudinal section of lupin flower

pollination by humble-bees. The flowers are showy, being massed in heads. The individual flowers (Fig. 260) have a highly char-

acteristic appearance, largely due to the irregularity of the petals. The sepals are fused together into a tube, but the petals, except for the two which form the keel, are quite free from one another. One of the petals forms the large standard at the back of the flower, one on each side constitutes the wing, and two in front form the keel. Enclosed within the keel are the stamens, ten in number, which are fused by their stalks and which surround the ovary. Five of the stamens reach the tip of the keel, but the other five are considerably shorter. The ovary consists of one carpel only, bearing seeds along its upper side, which represents the inturned margin of the leaf from which it is formed. As in the buttercup, the stamens are attached to the receptacle below the ovary, so that the latter is said to be superior in position to them. This type of flower is characteristic of a large family which includes peas, beans and clovers.

The method of pollination is, in this case, rather complex. The flowers produce no nectar and are visited solely for their pollen. The bee alights on the wings and its weight depresses them and also the keel, but not the structures inside the keel. Consequently, the stigma, which is carried by the long style to the extreme tip of the keel, comes into contact with the under side of the bee's body a very short time before the stamens and picks up any pollen there may be there. The pollen from the tip of the keel comes into contact with the under side of the bee's body very shortly after this. The tip of the keel contains a good deal of pollen, because the shorter stamens shed their pollen into the tube formed by their own stalks, and it is carried into the tip of the keel by the growth of the longer stamens and the immature stigma. Hive-bees are not heavy enough to work the mechanism satisfactorily, the heavier humble-bee being the chief visitor. In the later stages of the flower's history self-pollination is quite possible, as the stigma is in contact with a good deal of pollen inside the keel. The ovary in this case ripens into a pod or legume, which ultimately splits completely into two halves to liberate its seeds.

White Dead-Nettle.—The white dead-nettle (Fig. 261) represents a somewhat later stage, in which the five petals are completely fused together. In this case, two petals form the upper lip, there is one on each side, and one forms the lower lip which is slightly split into two. There are four stamens which spring from the base of the petal tube. The ovary consists of two superior carpels, each of which is divided into two, each part containing a single

ovule. The long style emerges from the centre of these four portions and the forked stigma is found between the two pairs of stamens.

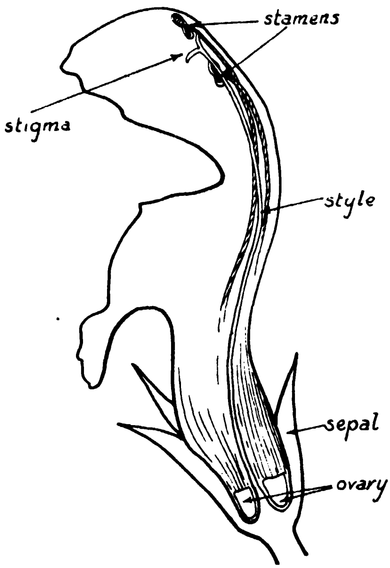


FIG. 261
Longitudinal section of white dead-nettle flower

Pollination is also effected in this case by humble-bees, which fit very closely into the flower. The bee alights on the lower lip and puts its head into the base of the flower to reach with its " tongue " the nectar at the base of the ovary. Only bees with a sufficiently long " tongue " to reach this nectar can effect cross-pollination. The effect of the bee's movements is that, as it enters the flower, the downwardly projecting lobe of the stigma collects any pollen from its back, and that, as it penetrates farther into it, the stamens come into contact with its back and more pollen is deposited there. The arrangement of the stamens and stigma does not by any means rule out the possibility of self-pollination.

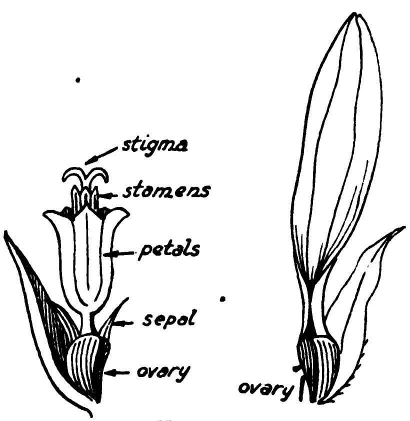


FIG. 262
Ray (*right*) *and tubular florets of Sunflower*
(*After Amy Johnson, " Text Book of Botany," published by Messrs. Allman & Son*)

Compositæ.—Unfailing cross-pollination has been brought to a fine art by the members of this very large and successful family of flowering plants. The individual flowers (Fig. 262) are small and inconspicuous, but they are typically massed together in very showy heads, consisting of an outer ring of ray florets with a mass of tubular florets in the centre. The former consist of five fused petals with no stamens and an

ovary from which projects a style and stigma. Sometimes, as in the cornflower, all the florets are of this type, while in the dandelion and thistles, they are not present at all. Both florets are well represented in such types as the daisy and the sunflower. The tubular florets have five regular petals fused together to form a tube, enclosing another tube composed of the anthers of the five stamens, which have fused together. The ovary is composed of two fused carpels and contains one seed only. The ovary is here said to be inferior in position to the stamens, since the point of attachment of the latter is above the ovary. Pollen from the stamens is shed into the anther tube, and is pushed up right out of the flower by the style, so that there is always a good deal of pollen scattered over the entire inflorescence. Self-pollination is impossible because the style continues to grow, and the bilobed stigma, with its fertile surface facing upwards, is well above the level at which pollen is found. Consequently many types of insect, chiefly bees of various kinds, which visit the flowers for nectar and pollen, pick up a good deal of pollen on their under surface. In crawling over the head, or a different head, some of this pollen is bound to be deposited on the upturned stigmas. If, by any chance, this mechanism fails, the stigma can grow outwards and downwards and pick up pollen from the same flower. It is very probable that this family owes its success to these highly efficient mechanisms, and also to its highly efficient seed-dispersal mechanism. The parachutes, which are found in many composites such as dandelions and thistles, are formed from structures which represent the sepals of other flowers.

Wind Pollination.—Examples of plants in which the pollen is blown from flower to flower by the wind are grasses and most trees. The individual flowers are usually small and inconspicuous, with an incomplete complement of sepals and petals. The structure of the flower of a grass is shown in Fig. 263. The stamens project from the flower in such a way that the light and dusty pollen may readily be blown away ; the stigmas are feathery, providing a large surface area. The flowers of trees are frequently massed together in catkins, though the flowers of willows and poplars which also have catkins, are insect pollinated. In most trees, some catkins bear flowers containing only stamens and others flowers containing only carpels.

Principles of Classification of Organisms.—Variations in the structure of flowers have been found to be the most reliable

FIG. 263
A. Single spikelet of flowers of the oat. B. Single spikelet fully open (After Amy Johnson, "Text Book of Botany," published by Messrs. Allman & Son)

characters on which to base a scheme of classification of the flowering plants. Many people are completely baffled by the scientific names of plants and animals, and simply cannot understand the necessity for such a scheme. A little thought will, however, show that the common names in use for plants are not nearly exact enough for scientific use. Thus, one may speak in ordinary conversation of the buttercup, but in practice there are a dozen different kinds and many others related to them. One can get a certain distance by adding a name denoting some special feature or the place in which they are commonly found, such as the creeping buttercup, or the bulbous buttercup (which has a corm), or the meadow buttercup, but this system is bound to break down sooner or later, particularly in the case of large groups. Some system of exact nomenclature is essential, together with a method of discovering which plant is which, so that whenever two people are talking about a plant they can be quite sure that they are referring to the same one. In general, scientific names are applied in much the same way as common names, and when translated they mean the same thing. Greek and Latin names are usually given so that they will be the same in every language. A name often refers to the discoverer of the plant or to some other person.

The inventor of the modern system of classification was Karl Linnæus, a Swede who lived from 1707 to 1778. Previous to this date, names had been very loosely given, plants sometimes having to be named by means of a whole sentence. Linnæus divided plants up into groups called genera, each of which is given a name which, in the case of the buttercup, is *Ranunculus*. This corresponds to its surname, and a more definite name is given to the subdivisions of the genus, which are called species. Thus, the creeping buttercup is called *Ranunculus repens*. Species are often split up into varieties, in which case a third name is added. The genera are grouped into families—in this case the Ranunculaceæ—and the families are in turn grouped together into larger units.

If it is required to find the exact name of a flower which has been discovered growing wild, it is always tempting to try to discover what it is by looking through a book which contains descriptions and illustrations and guessing which one it is. This method may be successful in the case of some rather striking flowers which have some readily identifiable feature, but the most likely result is further confusion. It is much wiser to become accustomed to using a flora, which is a book asking a series of alternative questions which, when answered by examination of the actual flower, lead eventually to the right name. A little experience is necessary before proficiency is likely to be obtained, as some of the questions are not as simple to answer as they sound, and often require the presence not only of the flowers but also the fruit of the plants concerned.

CHAPTER XXXIX

DISPERSAL OF FRUITS AND SEEDS

A FEW examples of fruits have been described in the previous chapter, but many other types are found. They are usually divided into dehiscent fruits, which split to liberate their seeds, and indehiscent fruits, which do not. Among the former are found capsules of many kinds, opening by pores, as in the antirrhinum and the poppy ; by splitting, as in the iris and the violet ; or by a transverse split, as in the scarlet pimpernel. The pod of the lupin and related plants is a dehiscent fruit which splits longitudinally. In the separating fruits of the geranium, the white dead-nettle and the sycamore, the fruit breaks up into single-seeded portions which do not themselves split.

There are many types of indehiscent fruit. Some are small, such as the achenes of the buttercup, and that formed from the two carpels of the inferior ovary of the composites. There is also a somewhat similar fruit to be found in the grasses, such as the wheat grain. Sometimes this kind of fruit is larger and is formed from several carpels, as in the thick-walled nut, and in the hazel, beech and the oak. Indehiscent fruits are commonly succulent, as in the berry of the gooseberry or currant, where the soft fruit wall encloses many hard-walled seeds. In the type of fruit termed the drupe, as in the plum, cherry and walnut, the fruit wall consists of three layers, the outer skin (epicarp), a soft mesocarp and a hard endocarp, enclosing the true seed or kernel. The blackberry consist of a mass of " druplets."

In some cases, the chief part of the fruit is formed by the fleshy receptacle, and these are technically known as false fruits (Fig. 264). Thus, the fleshy part of an apple is the receptacle which surrounds the inferior ovary represented by the core enclosing the seeds. Similarly, the fleshy part of a strawberry is the receptacle in which are embedded a number of achenes, each formed from a single carpel, as in the buttercup. The rose hip has a similar

structure, with the difference that, in this case, the achenes are enclosed within the receptacle.

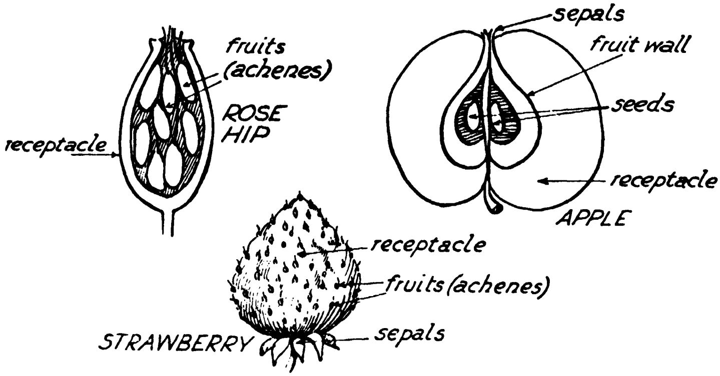


FIG. 264
Some "false" fruits

Dispersal of Fruits and Seeds.—If a plant is to be really successful and be present in large numbers over a large area, it is essential that the seeds should be spread as far from the parent plant as possible. A good illustration of this point is the great abundance over wide areas of many weeds, such as thistles and dandelions, all of which have extremely efficient methods of seed dispersal. If all the seeds produced by a plant were to fall on to a little patch of soil immediately surrounding the parent plant, there would be tremendous overcrowding, resulting in the death of many of the seedlings. It is much better that the seedlings should compete with other plants elsewhere than among themselves.

If the agents which might be utilized by a plant to help in the dispersal of its seeds are considered, it is found that nearly all those theoretically possible have been used. Seeds are commonly sufficiently small, sticky or prickly to be carried about by such moving agents as the wind, running water and animals. Tractors, motor-cars and bicycles also play a part in seed dispersal, for mud on the wheels and tyres has often been shown to contain the seeds of several plants. Charles Darwin once examined the mud on the foot of an injured water-bird, and found the seeds of nearly fifty plants contained in it.

The chief alternative to the methods mentioned above involves some sort of explosive method in which the bursting of the fruit

scatters the seeds to some considerable distance. A selection of methods will be given to illustrate the chief dispersal mechanism.

(*a*) **Dispersal by Wind** (Fig. 265).—Most seeds, particularly those which are fairly light, will be caught by the wind when they become detached from the parent plant. Some plants, such as many orchids, have such very tiny seeds that they are carried great distances without having any special adaptation at all. In many plants, particularly those in which the fruit only contains a single

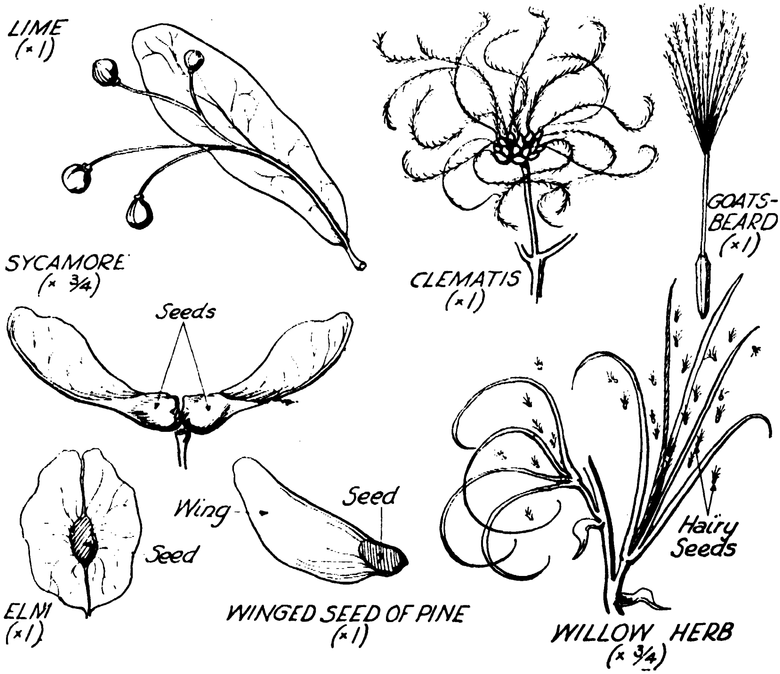


FIG. 265

Some fruits and seeds dispersed by the wind

seed, the fruit bears a wing or a collection of hairs, which exposes a large surface to the wind. Wings are found on the fruits of many of our deciduous trees, such as the sycamore, ash, elm, while the pine has winged seeds, which may be found between the woody scales of the cone.

A good example of a plant with hairy seeds is the willow-herb, with its long four-sided fruits full of cottony seeds. Cotton itself is prepared from similar hairs on the seeds of the cotton plant.

The best examples of adaptation to wind dispersal are found in the Compositæ, which include such examples as the thistle, goats-beard, dandelion and many others which have a definite parachute arrangement.

(*b*) **Dispersal by Passing Animals** (Fig. 266).—Many small unmodified seeds are caught in the fur of passing animals such as sheep and rabbits ; but it has been calculated that something like ten per cent. of flowering plants are distributed by the aid of outgrowths such as small hooks, which cause them to adhere tightly to animals. Familiar examples are cleavers and burdock, the fruits of which are provided with very definite hooks. Some animals carry away quite large seeds. Thus squirrels hoard nuts for their

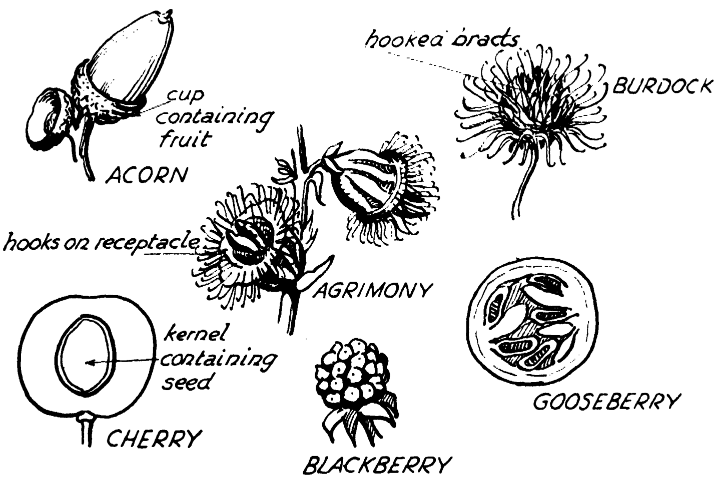


FIG. 266
Some fruits distributed by animals

winter sleep, and some of the larger seeds such as acorns are carried away by birds.

Animals, particularly birds, disperse many seeds contained in succulent fruits, which are fleshy and often brightly and attractively coloured. The birds eat the fleshy portion and either remove the fruit bodily, dropping the stone elsewhere, as in the case of sloes and cherries, or they may eat the fruit, the seeds being distributed in the birds' droppings, as in the case of strawberries, blackberries, hips and haws. In the last four examples, the apparent seeds are actually fruits, each containing one seed, since each is formed from a separate ovary.

(*c*) **Dispersal by Running Water.**—This is not a very common method as most of the plants which grow near or in water are distributed by the wind, but it does occur and the fruits and seeds concerned are, as might be expected, lighter than water and can keep afloat. Examples are water lilies and some sedges.

(*d*) **Dispersal without External Agency** (Fig. 267).—Many plants have no definite device for dispersing their seeds. For instance, in the horse chestnut the fruit simply splits and the large heavy seed falls out and bounces a considerable distance. Any explosive mechanism is usually due to different layers of the fruit

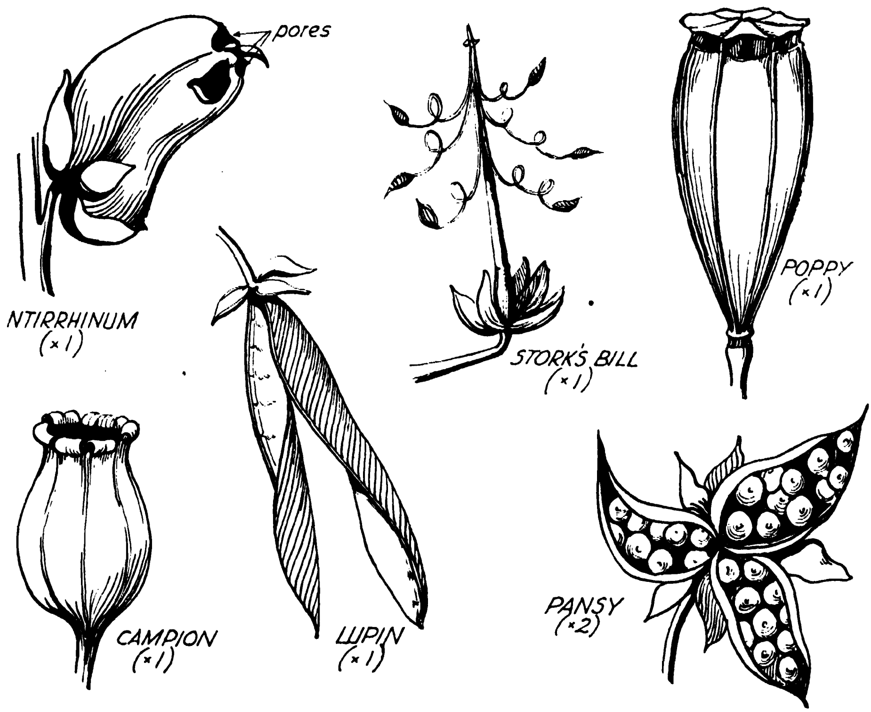


FIG. 267
Some dehiscent fruits

wall drying unequally in the sun, with the result that some layers begin to crack and eventually the fruit splits with a considerable force. This is a very common device, two examples being the sweet pea and the pansy. In the former the pod, which is like a pea pod but smaller and differently shaped, is found when split to

have very much twisted valves showing that tensions must have been set up in the pod before splitting. The fruit of the pansy splits somewhat violently into three pieces, each with a double row of seeds.

A third type is the so-called separating fruit, of which the Stork's Bill, a wild geranium, is a good example. The fruit here consists of five separate pieces each with one seed attached to the main axis. On drying out, these pieces become separate, fall off, and the part which does not contain the seed coils up and drives the seed into the ground.

CHAPTER XL

SOME SIMPLE ORGANISMS

IN the chapter dealing with cells and the differentiation of labour, it was mentioned that many microscopic organisms correspond in structure to a single cell of a more complicated organism, in that the protoplasm forming the body only contains one nucleus. These organisms may, therefore, be termed unicellular. Such an organism is Amœba, often quoted as one of the simplest animals. These organisms are practically colourless and are found on the surface of weeds, mud or stones in fresh water or in the sea. Amœba has nothing in the nature of a head, or limbs or bones or intestine. In fact it has very few of the things which we commonly think an animal must have. It consists of a mass of largely undifferentiated protoplasm, requiring the high power of the microscope for careful examination, and contains a single nucleus which can be shown up by the use of a suitable stain. The shape of the animal (Fig. 268), is constantly changing owing to its method of movement by means of the long, finger-like processes known as pseudopodia, which are thrown out in all directions. When the animal moves in any one direction, a pseudopodium flows out and the remainder of the protoplasm flows into it. New pseudopodia are then formed and the animal moves in another direction. This is called amœboid movement and is found in various other types of cell, notably in the white corpuscles in the blood.

Amœba feeds on microscopic plants called diatoms, and other small particles, which are engulfed by a pincers movement of two pseudopodia. Each particle is enclosed by a clear space called a food vacuole, into which a digestive juice is poured and the diatom is slowly dissolved, the undigestible material being left behind when the animal moves on. The only other structure to be found in the protoplasm is a spherical, clear space, which disappears at intervals, and slowly returns to its original size. There have been many speculations concerning the function of this contractile

vacuole. It has been suggested that it is an excretory and a respiratory organ, but it is more likely that it expels the excess water which enters the body when food vacuoles are formed. It is likely, too, that water is sucked into the organism over its whole surface osmotically, as the surface is semi-permeable and the internal solution is concentrated. Of course, this does not mean that there are no excretory products in the water which is expelled, or that there is no oxygen in the water which enters. Amœba respires and excretes waste materials over the whole of its surface.

As in more complicated organisms, part of the food material is stored, part respired and part built up into fresh protoplasm.

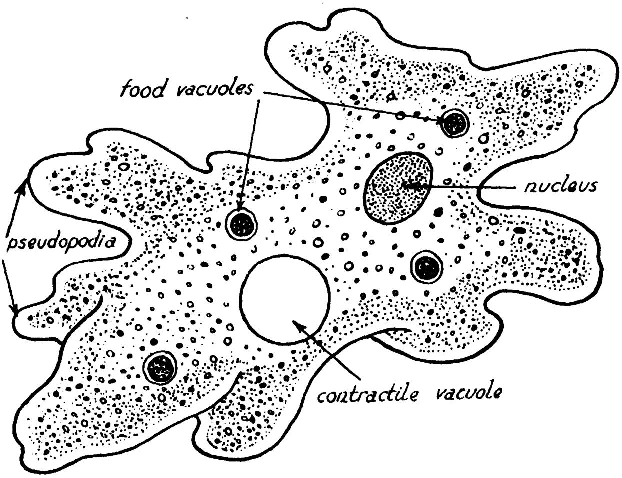


FIG. 268
Amœba

When Amœba reaches its full size, it reproduces in a strikingly simple fashion by simply splitting into two halves. The nucleus divides first, a constriction appears, and the two cells so formed now separate. This process is termed fission and is found in many simple organisms. Naturally, fission would be quite impossible in complex and highly differentiated organisms. This is the normal method of reproduction in good conditions, but, in poor conditions of food and temperature, the animal encysts. This means that it withdraws its pseudopodia, forms a comparatively tough outer coat, and remains in a dormant condition until circumstances improve. In this condition it is quite possible for an Amœba to be carried from one pond to another in the mud on a bird's foot.

Paramecium.—Paramecium (Fig. 269) is a microscopic animal which resembles Amœba in being unicellular, but which differs widely from it in structure and behaviour. It is very easy to obtain Paramecium in quantity for laboratory study, though it cannot be done quickly. Some hay is put into water, allowed to decay, and a little water containing Paramecia is added. The latter feed on the germs which are present in large numbers in the decaying hay, and multiply very rapidly. It has a definite shape which is related to the fact that it moves quickly through the water, and is streamlined in much the same way as the giant racing cars which have raised the land speed record to over 350 m.p.h. The propulsive mechanism consists of short threads called cilia, which are found all over the surface of its body. (In most animals the cells composing

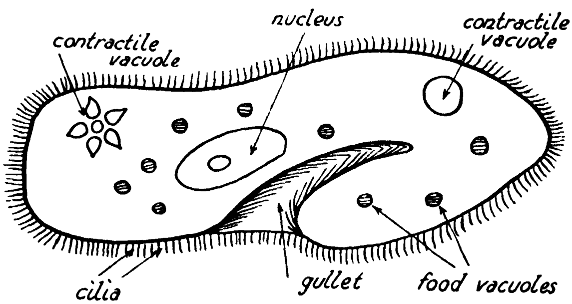


FIG. 269
Paramecium

several internal linings are provided with cilia which, by their lashing, serve to drive fluid in a definite direction. Such cells are found, for instance, on the roof of the frog's mouth and at the top of our own windpipe.) A slow-motion film of the beat of a single cilium shows that it beats quickly backwards but recovers its position slowly, the tip being slightly bent by the resistance of the water. The cilia do not all beat at the same time but one after the other, and the effect is to drive the animal rapidly forwards through the water. The irregular groove on the lower surface terminates in the " mouth " through which food, chiefly germs and other small particles, is ingested. This groove, termed the peristome, is lined by cilia which waft the food towards the " mouth." The food particles become enclosed to form food vacuoles as in Amœba, but they are then conveyed round the body twice in the course of the digestive process, and the undigested remains pass

out through a temporary anus near the hind end. There are also two contractile vacuoles which have definite positions on the upper side.

Paramecium has two nuclei, one of which is large and visible, the other small and embedded in the side of the larger one. Of the two, the smaller contains the material which is passed on to the next generation, the larger being apparently more concerned with the metabolism of the organism. In good conditions the normal method of reproduction is fission, which takes place at right angles to the long axis of the animal. There is also another method which corresponds to that in the higher animals, in which there is a definite fusion between nuclei from two different individuals. The details in this case are complicated and, as they are peculiar to this class of animals, it is not proposed to discuss the matter here.

Chlamydomonas.—This fresh-water organism, which is much smaller than Amœba or Paramecium, also has a very definite shape,

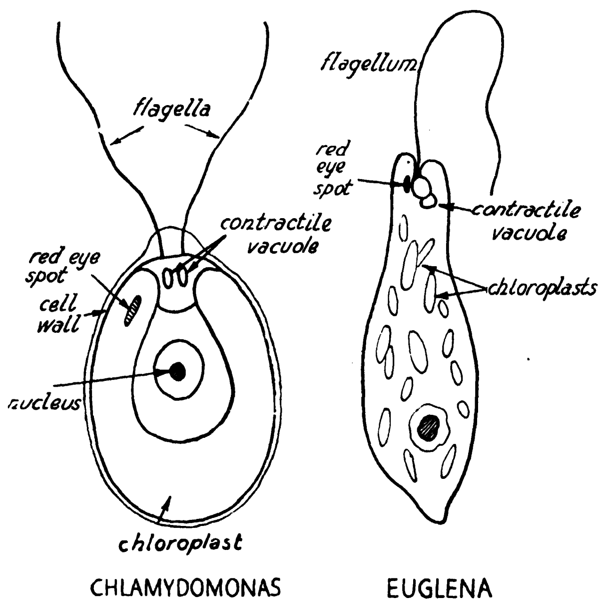


FIG. 270
Chlamydomonas and Euglena
(After Doflein)

due to the possession of an oval cellulose wall (Fig. 270). In front are two large cilia which, by their lashing, propel the organism

forwards. There are two small contractile vacuoles at the front end, and also a red eye spot which is reputed to be sensitive to light. By far the largest structure in the protoplasm is a cup-shaped chloroplast, which contains chlorophyll, so that the organism is green in colour. The nucleus is to be found in the hollow of the chloroplast. One or two small parts of the chloroplast show up very prominently : these are called pyrenoids and the starch grains, which are formed by photosynthesis from the carbon dioxide dissolved in the water, are formed round them. In good conditions Chlamydomonas reproduces by means of spores which are formed inside the cellulose wall and are not liberated until the latter decays or breaks in some way. Each cell splits into two after nuclear division, and then each daughter cell splits into two again, forming four spores, each very similar to a miniature adult, inside the wall. The word spore is a technical term for a one-celled reproductive body which is not formed by nuclear fusion. In bad conditions, such as bad light and low temperature or drought, Chlamydomonas reproduces in another way. When this happens, division goes past the stage of four spores and as many as sixty-four minute individuals may be formed from one parent cell. These products of division then fuse together in pairs, forming zygotes.

The individuals which fuse come, in some cases, from the same parent, in other cases from different parents. The cilia of the fusing individuals are withdrawn, the nuclei fuse together to form a single product, the cell secretes a thick wall round itself and rests until conditions are better.

Euglena.—Euglena (Fig. 270) is found in puddles, water-butts and similar pieces of water in which organic matter is decaying. It is very small—very much the same size as Chlamydomonas—and is also green. There is one flagellum (a large cilium), projecting from the " gullet " at the front end. The gullet is a depression similar to the peristome of Paramecium, though it is never used for the ingestion of food. Into the gullet opens a system of two contractile vacuoles, the inner discharging into the outer. There is, as in Chlamydomonas, a red eye spot at the front end. The organism moves by means of its flagellum, but it is also capable of changing the shape of its body as it has no cellulose wall, but merely a thin covering called a pellicle. These changes of shape are brought about by the contraction of fibres in the outer layer of the protoplasm. The nucleus is roughly in the centre, and the chloroplasts are found at the hind end of the body. In this case,

the product of photosynthesis is a substance related to starch, paramylum. Euglena also absorbs over its whole surface soluble organic compounds from the water. This method of feeding is termed saprophytic and is found in many plants, notably fungi. Euglena reproduces by longitudinal fission.

Spirogyra.—Spirogyra is a plant which consists of comparatively large cells arranged in the form of a filament. The filaments occur in tangled dark green masses on the surface of stagnant fresh water; and this particular example can always be recognized by its dark green colour and by the fact that it is very slimy to the touch.

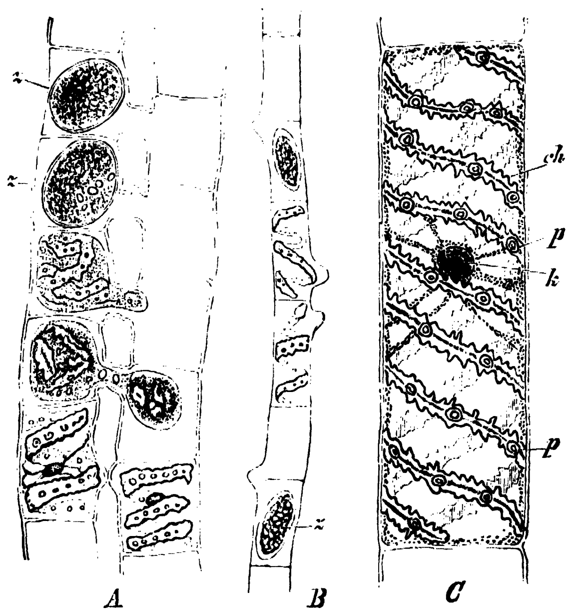


FIG. 271

A—Reproduction of Spirogyra; z-zygote. B—Reproduction of species of Spirogyra in which only one filament is involved; z-zygote. C—Single cell of Spirogyra; ch—chloroplasts; p—pyrenoid; k—nucleus

This is due to the secretion of mucilage by the cells. Each individual cell (Fig. 271) is cylindrical in shape, with a length of 20–30 μ, and a diameter of 5–10 μ. The protoplasm is found as a thin lining round the inner side of the cell wall, and there is thus a large vacuole full of cell sap. In the middle of the vacuole is a central piece of protoplasm suspended by " bridles " from the peripheral layer.

The chloroplasts, 2–12 in number, are arranged spirally round the outer part of the cell in the peripheral layer of protoplasm, this pattern being responsible for the scientific name of the plant—Spirogyra. Each chloroplast bears several pyrenoids, round which are found the starch grains formed in photosynthesis.

Each cell of this plant is morphologically and physiologically independent of all the others in the filament. This organism is chosen to be studied because it illustrates admirably the stage mentioned in a previous chapter, where there are a number of similar cells showing no differentiation of labour at all. Each cell builds up its carbohydrate from the carbon dioxide dissolved in the water, and its proteins by the combination of sugars with nitrates and other mineral salts, also obtained from the water of its environment. The growth of the filament proceeds by the division of individual cells into two, preceded, of course, by division of the nucleus; there is no definite growing region. Any individual cell which breaks off can grow into a new filament, and the normal method of reproduction in good conditions is fragmentation of the filament and the subsequent growth of each fragment into a new filament.

With the approach of unfavourable conditions, such as those of winter, the filaments become arranged in parallel pairs. Each cell puts out a small tubular process which grows towards its neighbour in the other filament, and the two processes fuse so that there is a clear passage between each pair of cells. The protoplasmic contents of the cells, including nucleus and chloroplasts, in one filament pass across these connexions, one in each, to the cells in the other. The nuclei of each pair fuse, and the cell which is the result of the fusion, the zygote, secretes a thick wall round itself. It is ultimately set free by the decay of the outer cell wall, sinks to the bottom, rests until conditions are favourable again, and then grows into a new filament.

The Differences between Animals and Plants.—The primary difference between an elephant and an oak tree is that they feed in different ways. The animal takes in organic food through its mouth, the plant possesses chlorophyll and builds up its food substances from very simple inorganic sources. The animal is therefore compact and moves from place to place in search of food. On the other hand, the substances needed by the plant are in the soil and in the air, and the branching nature of the plant is an admirable adaptation for obtaining an adequate supply of these

raw materials. A further difference is that plants store carbohydrates as starch, animals as glycogen. A structural point is that plant cells have a cellulose wall which animals lack. Amœba is an animal because it feeds in the typical animal manner ; Chlamydomonas a plant because, although it is capable of movement, it feeds in the typical plant manner. Euglena is, however, much more difficult to place. It has chlorophyll and stores a starch-like substance, but is also saprophytic. It lacks a cellulose wall and is capable of movement. Finally, it has a gullet which it does not use for the ingestion of food, though it is used in some nearly related forms which have a similar structure. It would seem that the distinction between animals and plants in this case means very little.

CHAPTER XLI

FUNGI AND BACTERIA

FUNGI are very familiar organisms in the countryside, especially during the autumn, and they constitute an exceedingly large group of plants. For instance, the mushroom and toadstool group includes something like 30,000 different kinds. The most obvious feature about them is that they are not green, for they have no chlorophyll. A fungus plant consists essentially of a mass of branching white threads termed hyphæ. A familiar example is Mucor, a very common white mould, which grows extensively on organic material such as jam, leather and bread. A copious supply can often be obtained on aged crumpets or by keeping horse dung moist under a bell jar. The filaments have no cross walls, but the protoplasm contains large numbers of small nuclei. As the plant has no chlorophyll, it is obvious that it cannot build up its own food. The filaments secrete enzymes which dissolve the organic material on which the fungus is growing, and the sugars and other soluble organic compounds so formed are absorbed. Mucor is thus a saprophyte.

Under favourable conditions, certain hyphæ grow vertically towards the light, and expand at their tips into spherical structures known as sporangia, which resemble pin-heads. The contents of this structure divide up into a large number of single-celled spores, each containing one nucleus. To these black sporangia the fungus owes its name of pin mould. The increasing turgidity of the structure termed the columella inside the sporangium (Fig. 272), eventually bursts the wall of the sporangium, and the spores are liberated. They are very small and are blown about in the air; this explains the fact that Mucor is so common.

In unfavourable conditions small outgrowths appear opposite one another on pairs of parallel filaments, much as in Spirogyra. These outgrowths continue to grow and eventually the terminal portions, each of which contains several nuclei, fuse together to

form a single structure known as a zygospore. The nuclei fuse together in pairs, one of each pair being derived from each parent. The central structure secretes a prickly black wall round itself and rests for a period. When it germinates, it produces a sporangium instead of growing direct into a mass of hyphæ.

The ordinary mushroom is a typical fungus which feeds saprophytically on decaying organic matter in the soil. The real plant consists of branching threads below the ground, the actual mushroom being a temporary structure which produces spores. The

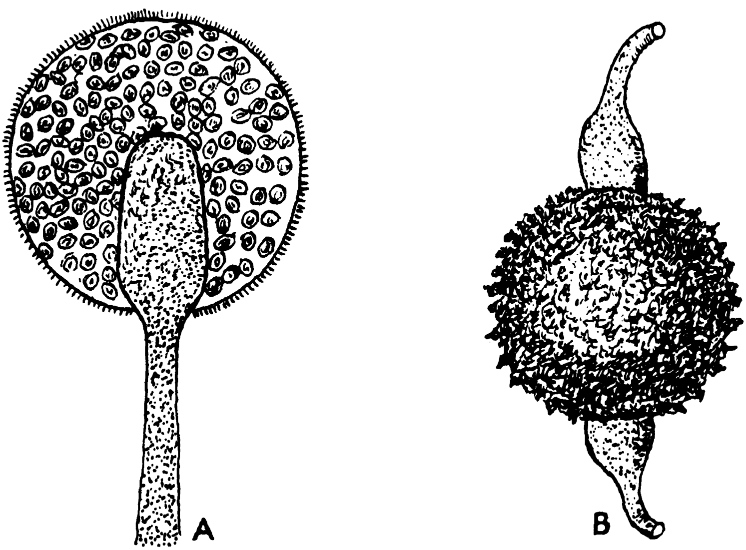


FIG. 272
Mucor. A. Sporangium. B. Zygospore

spores are borne on the gills, so called because they resemble the gills of fish. Many moulds and other types of fungi derive their organic food from living plants and do an enormous amount of damage to cultivated plants every year. Such fungi are said to be parasitic. Examples are the fungi causing such diseases as the damping off of seedlings, in which the fungus penetrates at ground level into seedlings which have been kept too moist, so that they topple over ; most diseases of potatoes ; mildews and blights of various kinds ; scab and brown rot in apples ; rust and smut of wheat, and many others. The activities of the hyphæ of the fungi producing large brackets on elm and other trees lead to the trees

becoming hollow and liable to be blown down. Fungi also cause many diseases in animals, such as ringworm, and some grow on the gills of fish. Many of the saprophytic fungi are also important economically, such as that causing dry rot of wood.

Yeast.—Yeast (Fig. 273) is a minute unicellular fungus. The nucleus is unusual in that it encloses a large vacuole. There are no chloroplasts, and the only other structures found inside the wall are granules of glycogen. When yeast is examined under the high power of a microscope ($\frac{1}{6}$ inch objective) it is possible to see the cells clearly, but not much inside them, except possibly the vacuole. More can be seen of the nucleus if the living cell is stained with dilute methylene blue.

The structure of yeast is, then, exceedingly simple, but its metabolism is unusual. The strains of yeast used in baking and brewing are cultivated strains, the wild varieties being found in places where a good supply of sugar is available, as on the skin

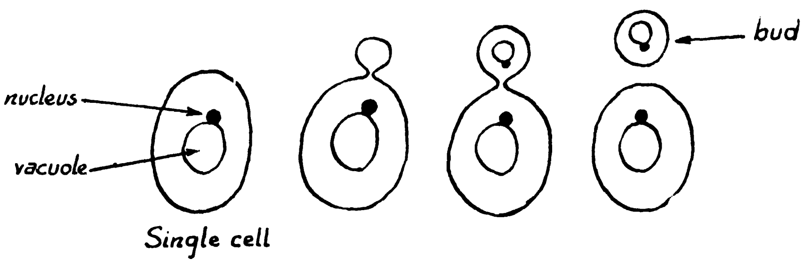


FIG. 273
The budding of yeast

of fruits and in the soil in vineyards. The yeast cells feed saprophytically, absorbing sugar and salts from the environment. When a little brewer's or baker's yeast is put into a solution of sugar, the solution begins to effervesce as if boiling, though a thermometer shows that there has been little rise of temperature. If a delivery tube is fitted to the flask and the gases given off led into lime water, it is seen that the large bubbles of gas causing the appearance of boiling are composed of carbon dioxide. If the cork is removed after a few hours, the mixture in the flask has a definite alcoholic smell. Some of the sugar solution absorbed by the yeast has been broken down to form alcohol and carbon dioxide according to the following equation:

$$\text{sugar} = \text{alcohol} + \text{carbon dioxide}.$$

If a drop of the liquid is withdrawn from the flask and examined under the microscope, the yeast will be found to have altered considerably in appearance. To most of the cells are attached smaller ones, and these are, in fact, buds which have been formed by unequal fission and constriction from the parent cells. This process goes on very rapidly in favourable conditions, and chains of cells are frequently formed. The energy for this rapid growth and reproduction must have come from that liberated in the breakdown of sugar. The importance of the process is that oxygen is not employed in this type of respiration, for such it is. In ordinary, or aerobic, respiration, the sugar is oxidized completely to carbon dioxide and water and, as the waste products are such simple compounds, practically all the potential energy of the sugar is liberated. Yeast can live aerobically like any other organism, but when it is in contact with sugar solution but out of contact with air, it can still respire anaerobically without the use of oxygen at all. In this case, however, alcohol is still a complex compound and it still contains a great deal of energy, so that, when the two processes are compared, anaerobic respiration is much the more expensive in material, the amount of energy liberated from the same quantity of sugar being roughly in the ratio of one in anaerobic to fourteen in aerobic. Anaerobic respiration is by no means confined to yeast, but is found in many organisms, such as internal parasites and other creatures which live in regions where there is little if any oxygen. Most of the fungi are capable of it and so, indeed, is flowering plant tissue. This can be shown by introducing a few moist pea-seeds into an inverted glass tube full of mercury. They produce carbon dioxide although no oxygen is present, and the mercury is pushed down in the tube.

The breakdown of sugar by yeast was originally, and still is, called fermentation (derived from the Latin word *ferveo* = to boil), and it can be shown to be brought about by a substance present in the yeast protoplasm. This is called zymase and was one of the first enzymes to be isolated. It is not, of course, by any means the only enzyme that yeast possesses, as yeast has a complete complement of the carbohydrate, fat and protein enzymes necessary for building up new protoplasm and for other metabolic processes. As in other organisms, fats are formed from carbohydrates and proteins are synthesized from sugars and inorganic salts, particularly nitrates, sulphates and phosphates. Yeast is unusual in that it can make use of nitrogen in compounds other than nitrates.

When yeast is grown in a culture solution, it is usual to employ ammonium tartrate or other ammonium salt for this purpose.

Yeast is extensively used in baking and brewing. In baking its function is to make the bread "rise" by charging the dough with bubbles of carbon dioxide. The initial stage in brewing is the formation of malt from barley grains by allowing them to germinate, and then killing the germinating seeds by heat. During germination the reserve starch in the barley is converted to sugar by the enzyme diastase, and is extracted by grinding up the malt and dissolving out the sugar with water. Yeast is now added to this extract, together with hops for flavouring purposes, and more sugar is usually added too. The liquid is now allowed to ferment in large copper pans, and the yeast increases in bulk very rapidly, owing to budding. This is skimmed off and used in making various preparations containing yeast. The yeast actually used in brewing is specially cultivated for the purpose ; success in brewing depends partly on this factor, partly on the blending of hops from different sources, and partly on the temperature at which the liquid is allowed to ferment. In the brewing of beer, fermentation is stopped when the quantity of alcohol has reached a moderate figure, varying from 3 to 7 per cent. In the production of spirits, fermentation is allowed to go on for much longer, and different raw materials are sometimes used. In the case of brandy, more of the starch in the barley is converted into sugar before fermentation begins, and the product is distilled so that the percentage of alcohol in the final product is high (65–70 per cent.). In the case of cider and wines, the fermentation of the apple or grape juice is natural as the yeasts involved are found on the outside of the fruit.

Spontaneous Generation.—Aristotle (384–322 B.C.), the Greek philosopher and biologist, whose observations and ideas dominated biological thought for fifteen hundred years until more accurate work was possible, thought that some animals developed from eggs and that others, including sponges, jelly-fish and many shell-fish, arose from non-living material. Some fish, he thought, arose from mud or sand. Mice were considered to arise, under certain conditions, from grains of wheat, maggots from decaying meat, and lice and fleas from dirt. By the seventeenth century most of these stories had been disproved by careful experimental work and by the use of the microscope. The latter revealed, however, the presence of many exceedingly minute organisms, now known as bacteria or germs, in decaying organic material and once again

the idea of spontaneous generation found many champions. The question was finally settled by the brilliant researches of the Frenchman, Louis Pasteur, in the middle of last century. His work on bacteria began with investigations into the souring of milk and the " diseases " of wines. He became convinced that fermentation of sugar was caused by minute organisms, and he successfully worked out the life history of many of them. Some were yeasts, others were bacteria. He also thought that the changes involved in putrefaction or decay were due to these organisms.

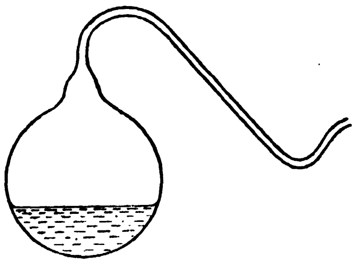


FIG. 274

The question of the spontaneous origin of these organisms naturally arose. Pasteur was successful in showing by experimental means that they do not arise in this way. The essential feature of the flasks used was that the neck was drawn out into a narrow **S**-shaped tube. The flasks (Fig. 274) were filled with meat broth, and subjected to prolonged heating at 100° C. The flasks were then left undisturbed for several weeks, the end of the tube remaining open to the air. No fermentation took place. Broth in similar flasks treated in the same way soon fermented when the tube was broken off near the flask, and it was possible to demonstrate the presence of bacteria within a few hours. In the first case the bacteria present in the air were caught in the lower part of the **S**-tube, and the air currents were not sufficiently strong to carry them into the flask. In the other case the bacteria obtained entry at once and fermentation began very quickly. Pasteur concluded his famous lecture on this subject : " Never will the doctrine of spontaneous generation recover from the mortal blow of this simple experiment," and so it has proved.

The Cultivation of Bacteria.—It was soon realized that bacteria were the cause of many diseases, such as anthrax, hydrophobia, tuberculosis and cholera. The general method of research was the isolation of the bacterium from the animal and the subsequent injection of a quantity of them into healthy animals which soon contracted the disease. A German doctor, Robert Koch, was responsible for the discovery of a method of culturing bacteria outside the body, and of separating the various kinds. So important was this step that in the following ten years (1881–91) most of the

germs causing diseases were discovered. The principle of Koch's method was the use of a solid medium instead of a liquid such as broth in order that the products of division of each individual bacterium present on it should not mix, but form colonies which could be dealt with separately. The nature of the medium varies

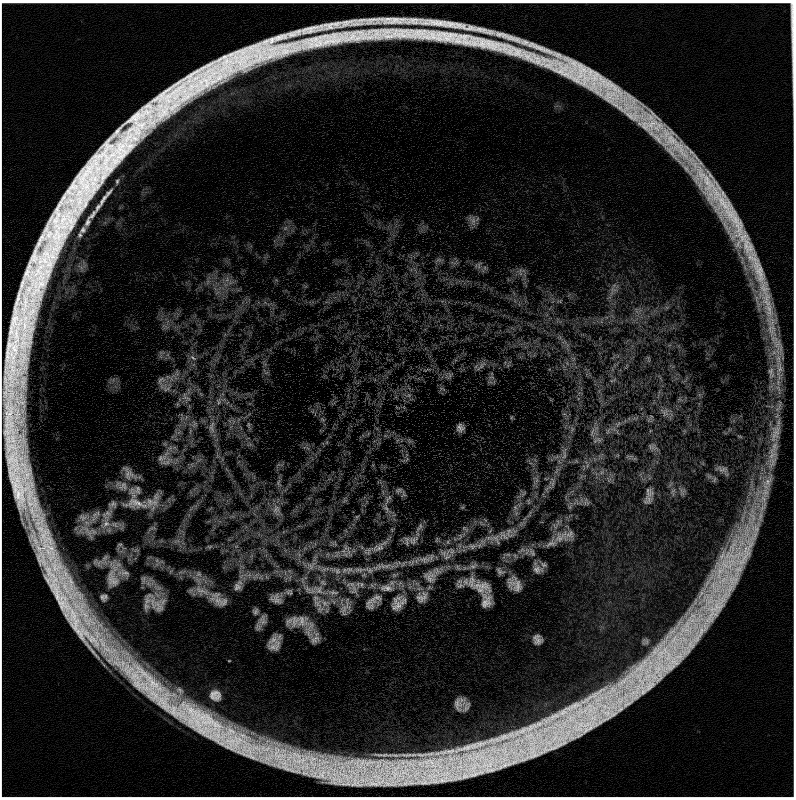


FIG. 275

widely with the nature of the bacterium under investigation. The bacteria present in the air may be cultured in Petri dishes filled with gelatine which has been boiled with the extract of raisins. Another common medium is agar jelly containing the extract of potatoes. Both dish and medium must be made free from bacteria before the experiment is begun, an operation which may be carried out by one of the methods described below. When the medium has

cooled, the upper part of the dish is removed for a few moments and then replaced. An exactly similar dish should be used as a control and not exposed to the atmosphere. The two dishes should now be incubated and in a few days bacterial colonies will appear in the dish which was exposed. Fig. 275 shows a Petri dish containing a medium on which a fly was allowed to walk. Some of the bacteria present on the legs of the fly became detached and have formed colonies. Fungi such as Mucor may also be cultured in this way.

Structure and Reproduction of Bacteria.—Bacteria are exceedingly small, and a $\frac{1}{12}$-inch objective is essential to see them reasonably well. They are rod-shaped (bacillus form), spherical (coccus form), or spiral (spirilla form), and may or may not possess flagella (Fig. 276). They are non-cellular and have no nucleus. They do not contain chlorophyll and must therefore be parasitic or saprophytic. About a third are parasitic, and a few of these cause diseases. Most parasitic bacteria are quite harmless, and

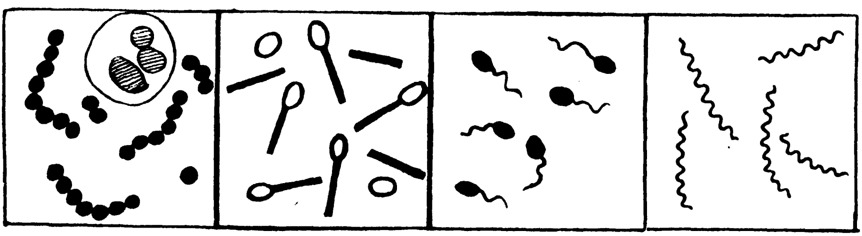


FIG. 276

Bacteria (L to R). Streptococci (which are responsible for many kinds of inflammation); a white blood corpuscle is also shown. Bacillus tetani (which causes lockjaw), with and without spores. Nitrosomonas (p. 411): Spirilla form

some, such as that found in the mammalian large intestine (p. 276), are actively useful. The majority of bacteria absorb organic compounds from decaying organic material (Chap. XLV). Under favourable conditions they reproduce very rapidly by binary fission, which in some cases may take place every twenty minutes. When conditions become unfavourable, many of them produce spores. Each bacterium produces one spore only, which later grows into a single bacterium, and the spore is thus not a reproductive but a resting body.

Sterilization.—A revolution in surgery followed the discovery

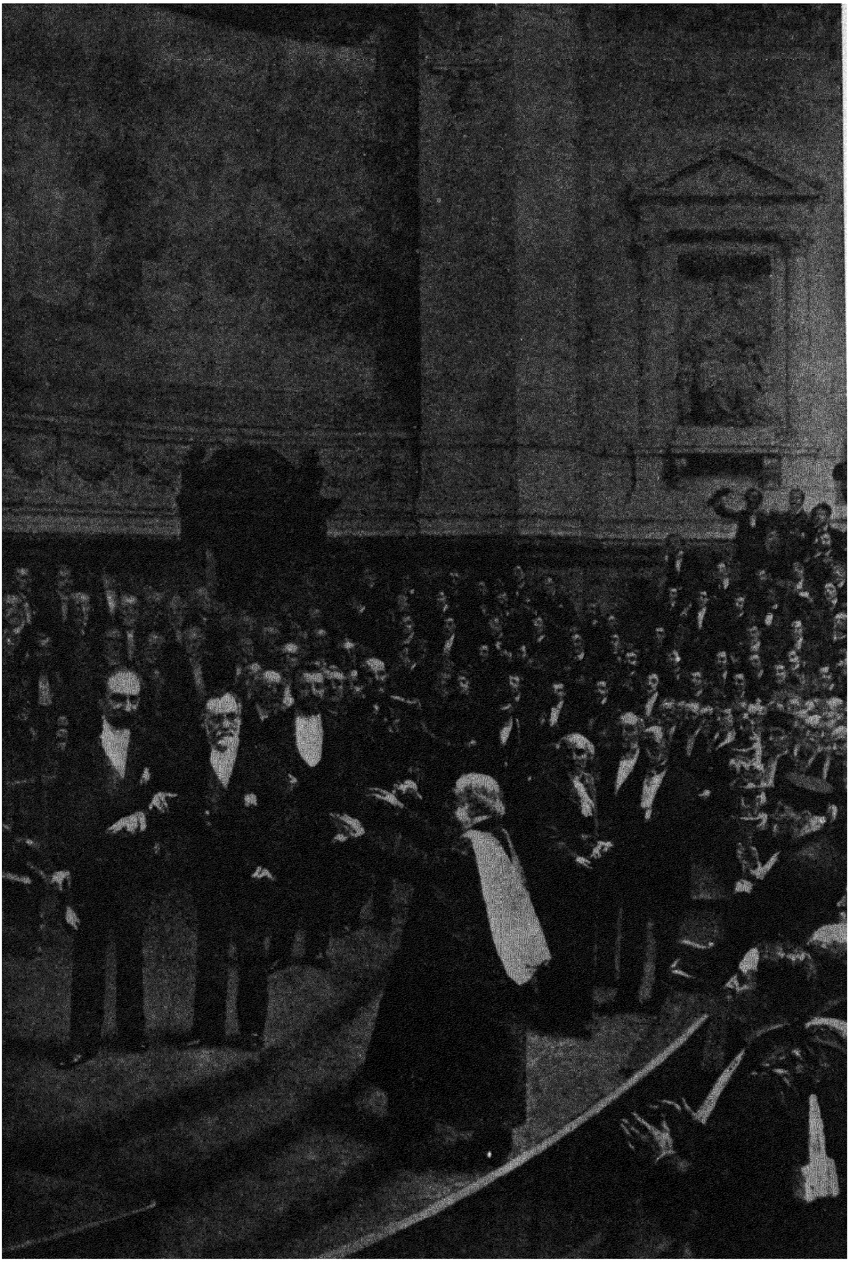


FIG. 277

The meeting of Pasteur and Lister at the Sorbonne, during the celebration on December 27, 1892, of Pasteur's seventieth birthday

that the pus which accumulated in wounds after operations was due to the entry of bacteria known as streptococci. A Glasgow surgeon, Lister, introduced methods of cleansing of surgical instruments, dressings, the surgeon's hands and the patient's skin which enabled wounds to heal rapidly and cleanly. If such sterilization is to be successful it must be very thoroughgoing, as bacterial spores are very resistant to extremes of heat, cold, drought and other unfavourable conditions. They are present in the air in vast quantities, and in fact in every conceivable place to which air can penetrate. A dry heat of about 150° C. for an hour is probably the most effective method of sterilization in cases where it can be used. In some cases light or X-rays can be used. For liquids and dressings an autoclave heated by steam under pressure is the best method. Milk, which cannot be heated to such a high temperature without gravely impairing its quality, is heated to about 70° C., a process known as pasteurization. Bacteria can be rendered inactive by refrigeration, a method which is used very successfully in the preservation of food. The other chief method of sterilization is the use of substances termed antiseptics, which poison bacteria. Antiseptics in common use are alcohol, carbolic acid, iodine and many fluids sold under trade names. The bacteria in polluted water are killed by chlorination (p. 215).

CHAPTER XLII

DISEASE

THE last century has marked a tremendous advance in the knowledge and treatment of disease. Many factors have been responsible, but first and foremost comes the gradual realization that absolute cleanliness is one of the prime essentials in its prevention. In previous centuries, bad sanitary conditions and unsatisfactory methods of disposal of refuse led to circumstances in which diseases of various kinds were completely uncontrollable. Cleanliness, in the modern sense, was quite unknown, and patients regularly died from diseases contracted after they reached hospital. Anyone who knows anything of the rigours of modern surgery and hospital practice will realize the possibilities attaching to a complete ignorance of the mere existence of bacteria. Anæsthetics did not come into use until about 1850. Previous to this, patients were rendered unconscious by means of alcohol or by such drugs as opium. Laughing gas and ether were first used in America in the eighteen-forties. The properties of chloroform were discovered in 1847 by James Simpson, a professor at Edinburgh.

Organic Disease.—Not all diseases, of course, are due to bacteria or even to living organisms at all. Many of them are termed organic, in the sense that some organ or tissue fails for some reason or other to maintain its proper function. Thus, the disease known as osteo-arthritis is a condition in which the cartilage which lubricates the joints between bones becomes fibrous and inefficient. This is nothing to do with bacteria at all, and is largely due to " wear and tear." Many well-known diseases are due to the fact that one or other of the ductless glands (see p. 337) is under- or over-sized and the wrong quantity of hormone is being produced from it. Thus one form of goitre is due to an over-sized, and cretinism to an under-sized, thyroid gland. In this type of abnormality it should be possible to increase or decrease the supply of hormone by some artificial means, and this has been done in

some cases with complete success. One of the best-known cases is the treatment of sugar diabetes due to the discovery of the existence of the hormone, insulin.

Diseases connected with Food.—Certain other diseases have been shown to be due to a badly planned or inadequate diet. Many intestinal disorders are due to over-liberal meals and to meals providing the wrong proportion of foodstuffs. It is quite obvious that, in any case of illness, the diet of the patient is of first-class importance, and the practice of eating less and choosing more carefully is undoubtedly on the right line. This question was discussed in the chapter on food, but it is worth recalling that certain diseases are due to the absence of vitamins. Thus, such diseases as scurvy and rickets have been shown to be directly due to the absence of vitamins C and D respectively, and if an adequate supply of these substances is forthcoming these diseases will not arise, provided that, in the latter case, there is an adequate supply of raw materials for the hardening of the skeleton.

Diseases due to Germs.—There are, unfortunately, many examples of diseases caused by bacteria, which may obtain an entrance to the body in various ways. In the case of tetanus or lockjaw, the bacteria are present in soil, and infection in this case is due to the contamination of an open wound by soil containing these bacteria. In the case of tuberculosis, the bacteria may be inhaled with infected dust, or in milk which has come from tuberculous cows. There are, of course, very many kinds of bacteria which live in the body without causing any damage at all, but those which cause diseases produce, in the course of their metabolism, substances termed toxins which affect our bodies adversely in various ways. The blood responds by producing substances known as anti-toxins, which neutralize the harmful effects of the toxins. The rise in the temperature of the blood of a patient suffering from a fever is due to the activity of one type of white corpuscle, which engulfs and digests the bacteria responsible for the disease.

It has been found possible to combat the activities of these bacteria in various ways. The method of vaccination was first used by the Gloucestershire doctor, Edward Jenner, in 1798. He thought that there was some connexion between smallpox and a very similar disease of cows, termed cowpox. Although nothing was known at this time of the existence of bacteria, Jenner conceived the idea of injecting a small quantity of a preparation termed

vaccine, from an infected cow, into a healthy man, thereby inducing the mild disease, cowpox, in the man and stimulating his blood to produce substances to neutralize the harmful effects of the vaccine. Consequently, if the man subsequently fell a victim to smallpox, these antibodies were already present in his blood and the really serious disease was thus prevented.

This idea of acquired immunity to disease was a great step in the history of preventive medicine, but no further progress was made until Pasteur demonstrated so conclusively the rôle of bacteria in disease. He was able to extend the method of preventive inoculation to many other diseases. This part of his work began with the discovery that, in the case of a disease found in fowls, a bird inoculated with a stale culture of the particular germ actually recovered, and was then immune to inoculation with the really virulent germs. This led to a famous experiment in which he very conclusively showed that sheep, inoculated with a weak culture of anthrax germs, were immune to the disease, whereas any which were not inoculated rapidly succumbed if inoculated with the strong culture. The method was later extended to hydrophobia or rabies, and similar methods in connexion with other diseases have been extremely successful. The procedure is not always exactly the same as that described for anthrax. Thus, the injection given in cases of diphtheria is actually the blood serum of a horse which has been inoculated with the diphtheria germ, and which thus contains the requisite antibodies. In other cases, as in anti-typhoid inoculation, the material injected is a fluid containing dead typhoid germs in order to produce the requisite antibodies without any fear of the patient becoming a victim to the active disease.

It has become increasingly clear in recent times that many infectious diseases are caused by exceedingly minute creatures which are much smaller than bacteria, and which are, in fact, too small to see even under the highest power of the microscope. They cannot be filtered out from solution and are consequently known as "filter-passing" viruses. Diseases for which they are responsible are measles, mumps, influenza, colds, scarlet fever and many others. The methods of treatment follow closely those employed in the case of bacterial diseases.

Diseases connected with Parasites other than Bacteria.— Many diseases are caused by parasites of a different nature from bacteria and viruses. Fungi cause diseases in most plants and

many animals, but the only important human disease in which they play a part is ringworm. Small round worms cause a few diseases, but by far the most important class of disease-producing animal is the Protozoa, the group of unicellular organisms to which Amœba and Paramecium belong. In fact a creature very closely resembling Amœba is responsible for one form of dysentery. One of the best-known examples of this class of organism is that responsible for malaria. Various methods of the entry of disease-producing organisms into the body have been mentioned, such as through wounds, in food, through the nose and so on. The malarial organism provides an example of another method of entry, as it is transmitted from man to man by a blood-sucking insect—the mosquito. As described in Chapter XXXVII, the mosquito makes a puncture in the skin by means of its proboscis, and injects a little saliva which prevents the blood from clotting and thus ensures a continuous flow of blood. The saliva of some kinds of mosquito contains malarial organisms and they are transmitted from man to man in this way. Of course, if an uninfected mosquito bites an infected man, the positions are reversed since the parasite lives inside the red blood corpuscles, some of which pass into the mosquito. In the latter, the malarial organism passes through some of the stages in its life history, resulting in the production of large numbers which find their way into the salivary glands.

The disease itself is a type of fever which recurs at intervals of a few days. It is not unknown in England, but is very rare, because English mosquitoes are not often infected with the parasite. This recurrence is due to the fact that, at these periods, the parasite undergoes division into some thirty or forty small bodies which are released into the blood. Each of these bores its way into a new corpuscle and more and more become infected in this way. The treatment consists of the application of quinine, a substance extracted from the South American cinchona bark, either by injection or by means of the mouth. This substance is only effective when the parasites are free in the blood, but other drugs have more recently been found to be more widely effective. Quinine remains, however, by far the most important substance used. Sometimes the parasites remain dormant for a long time, and malaria is really a more or less prolonged struggle against the resistance of the patient. If the latter is weakened by other illnesses or in any other way, relapses are likely to occur.

It is obvious that in all cases of infection completely successful treatment depends upon a really accurate knowledge of the life history of the parasite and of the insects or other animals which transmit it. Malaria was one of the first diseases to be studied along these lines, following the discovery by Sir Ronald Ross in

(From a Mauritian Newspaper, 1908.)

FIG. 278

Sir Ronald Ross

1898 that the disease is transmitted from man to man by mosquitoes (Fig. 278). Something can be done to keep out mosquitoes from houses by means of nets and so on, but the life cycle of the mosquito, as described in Chapter XXXVII, shows that there is one stage in which the mosquito is very vulnerable to scientific attack, namely in the aquatic larval stage, which is found in small patches of water

and which has to come to the surface to breathe. The first step in the eradication of mosquitoes is, thus, to drain marshy ground and any possible breeding-places, and secondly to cover any un-drainable areas with a layer of oil. Oil so lessens the surface tension of the water that the larvæ are unable to support themselves on it, and are thus asphyxiated (Fig. 254). Wherever these measures have been adequately put into operation, malaria has ceased to become a serious problem. The problem of sleeping-sickness in Central Africa, which is transmitted by tsetse flies, is much more difficult, since the young as soon as they are born immediately burrow into the ground.

CHAPTER XLIII

REPRODUCTION

ORGANISMS produce offspring in many different ways, but all fall under one of two headings. In some cases, as described in the flowering plant (p. 352), Chlamydomonas (p. 369), Mucor (p. 373) and Spirogyra (p. 371), the fusion of nuclei, which is termed fertilization, is involved. Such organisms are said to reproduce by means of the sexual method. In most plants and in many simple animals there is an alternative asexual method, as in the case of the production of spores by Mucor and other plants. Asexual methods, which do not involve spore production, are said to be examples of vegetative reproduction.

Vegetative Methods in Plants.—The binary fission of bacteria (p. 380) may be said to constitute the simplest example of this method. The budding of yeast is an example of fission in which the products are unequal in size. The filaments of Spirogyra grow in length by means of cell division and, when mature, frequently break into smaller filaments, each of which grows into a new plant. The richest variety of methods is found in the flowering plants, and many of these are made use of by gardeners. Vegetative reproduction and perennation by means of bulbs, corms and tubers have already been described (Chap. XXV). Another method is that of the strawberry, which produces runners, branches which grow horizontally above the ground, and root at a node. Connexion with the parent plant is lost naturally or artificially and a new strawberry plant is obtained. Carnations are propagated by the "layering" of creeping stems, that is, by fixing the latter firmly to the soil and cutting through the internodes. The rhizomes of many plants are very effective in forming new plants. Every year sees a growth in length of the rhizome, an increase in the number of shoots from the plant, and an increase in the number of plants if the connexion with the parent plant is lost. A number of garden weeds, such as ground elder, twitch grass and horsetails,

fall into this category, and it is exceedingly difficult to free a garden from them unless the rhizome is completely removed. The bracken fern has made such strides in this way in recent years that it has become a serious problem in many upland pastures.

In some lilies, a curious bud known as a bulbil is formed in the position where a flower-bud would normally be found. This drops off and grows into a new plant. The name is due to its external resemblance to an ordinary bulb.

In some plants roots can be induced to grow out of stems or even leaves and new plants formed in this way. Naturally, gardeners make very good use of the opportunities thus afforded them, especially in cases where, for various reasons, it is difficult, expensive or slow to raise plants from seed. In the cultivation of begonias, for instance, it is possible to produce new plants by slitting the leaves and keeping them moist. Whenever young shoots, which are cut off and planted in soil, can be relied upon to " strike," as in the garden geranium or pelargonium, these cuttings are employed for propagation. At the present time, several commercial preparations are on sale which make the propagation of plants by cuttings much easier, because suitable treatment of the cutting with the preparation has been shown to produce a copious growth of roots on cuttings of nearly all soft-stemmed plants. The commercial possibilities of these products have not yet been by any means fully exploited, and they will undoubtedly be widely used in the future.

Grafting or budding is a very ingenious form of artificial propagation which is only used in certain cases. It is used mostly in the case of plants in which there are a large number of cultivated varieties, such as fruit and rose trees. The problem is that, for reasons to be explained shortly, the seeds of a garden variety of these plants do not grow up into plants of the same variety, but into a number of different varieties. A twig or bud is very carefully cut from the required variety so that the piece removed has a tapering end, which is then introduced into a similarly shaped depression in the plant which is to form the stock. The piece introduced, termed the scion, is carefully bound into position so that it is well supported and there is no possibility of any fungal infection. The wounding stimulates the tissues of both plants to grow more quickly for a time. The tissues of the two become mingled so that the scion continues to grow and ultimately produces the flowers and fruits of the required variety although attached to a different, though closely related, plant.

Asexual Methods in Animals.—The simplest form of asexual reproduction is fission, as in Amœba and Paramecium (Chap. XL). Some unicellular animals, such as the malarial parasite (p. 386), produce structures which may be termed spores. Hydra, which is found attached to twigs and weeds in ponds and streams, is a very simple animal which, in addition to reproducing sexually, also produces "buds." The animal itself consists of two layers of cells separated by a layer of gelatinous material. The mouth leads into a large digestive cavity lined by the internal layer of cells. The bud (Fig. 279), in this case, is an outgrowth of the side of the body which continues to enlarge until it acquires a mouth and breaks off from the parent. The two layers of cells, the jelly and the digestive cavity of parent and bud are continuous until a late stage. If some animals of this grade of organization are cut into a number of pieces, each piece will grow into a new animal. Several simple worms, both freshwater and marine, produce buds one behind the other, each with a separate head. In this connexion it is noteworthy that an earthworm cut into two may grow into two completely new worms and that a crab may slowly replace a limb which has been lost.

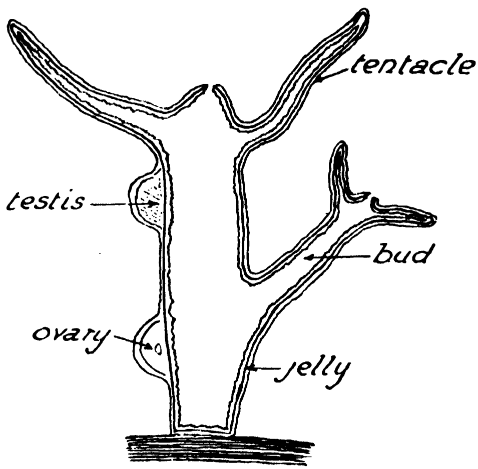


FIG. 279
Hydra with bud

The Sexual Method.—The sexual method, as previously pointed out, involves the fusion of two nuclei, one from each of two specially prepared cells, usually, but not always, derived from different parents. The specially prepared cells are known as gametes, and their fusion is known as fertilization. In the more complicated animals reproduction is only possible in this way. In plants the method is almost always employed at some point in the life history, the only exceptions being the bacteria and many of the fungi.

In the simplest organisms, such as Chlamydomonas, the cells which fuse together are produced by the repeated division of the parent cell, but they are essentially the same as the parent cell and have all the structures possessed by the latter. All the gametes are exactly the same in size and structure, and behave in exactly the same way. They fuse together in pairs, the nuclei fuse and the resulting cell, termed the zygote, grows into a new individual. If they do not fuse they are still capable of growing into a new individual. Thus it is clear that the words male and female have no meaning in this case at all and have nothing to do with the essential meaning of sex.

In one species of Chlamydomonas certain individuals, indis-

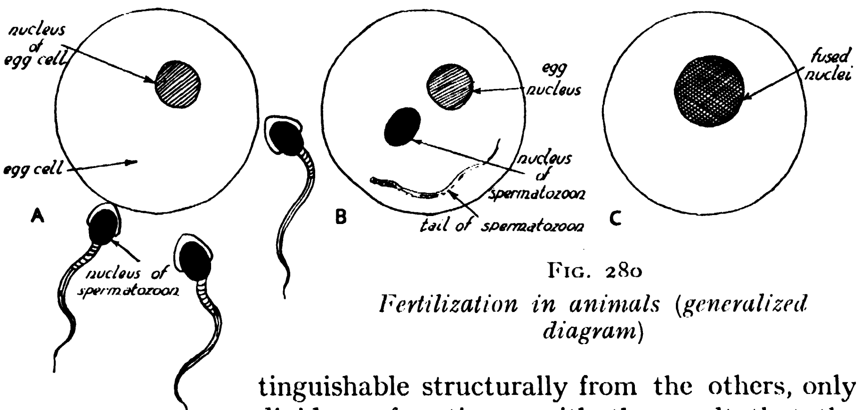


FIG. 280
Fertilization in animals (generalized diagram)

tinguishable structurally from the others, only divide a few times, with the result that the gametes formed are considerably larger than normal. They are, too, more sluggish in behaviour, and fuse with one of the smaller and more lively gametes formed from another parent. In practically all animals and plants the same process has gone very much further. Not only are there two kinds of gametes, but they are produced by separate male or female individuals. The gametes are produced by special organs, the testes of the male and the ovaries of the female. The larger gametes, the female or egg cells, are motionless and swollen with food reserves, and are much larger than the male gametes or spermatozoa, which contain very little food material. Each spermatozoom has a head which consists almost entirely of the nucleus, and a tail by means of which it swims actively to reach the egg. In the majority of simple aquatic animals such as jelly-fish and starfish, the egg cells and spermatozoa are shed into the water and fertilization occurs there.

Though each egg is surrounded by a large number of spermatozoa, only one of the latter penetrates into the egg. The nuclei of the spermatozoon and the egg cell fuse together (Fig. 280) and the egg cell thus fertilized is now capable of growing into a new individual. The surplus spermatozoa cannot grow up into new individuals, but they contain such little food material that this wastage is more apparent than real.

In the frog, the eggs, which are the black spheres seen in frog spawn, are large and contain a large quantity of yolk, which is food

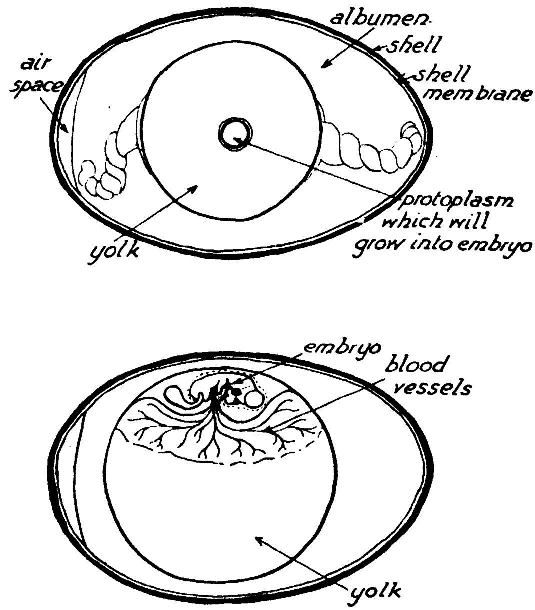


FIG. 281

Hen's egg before incubation (above) and after incubation for five days

material later used by the developing tadpole. The spermatozoa are shed over the eggs as they emerge from the female and fertilization takes place inside the jelly which is characteristic of frog spawn. In birds, fertilization takes place in the body of the female. The number of eggs is in birds comparatively small. The word egg, when used in connection with birds, may mean the egg which corresponds to the egg of a frog, namely the part usually referred to as the yolk, or it may mean the shelled egg. The hen's egg, as seen in Fig. 281, is a complicated structure in which the young

bird develops when incubated. The layers outside the true egg, namely the " white," the shell membranes and the shell itself, are laid down round the true egg after it has left the ovary. The embryo develops from a layer of protoplasm on one side of the yolk. The yolk consists of food substances which are transferred to the developing embryo in solution in the blood. The oxygen necessary for the respiration of the embryo is obtained through the shell, which is porous. The chick hatches from the egg in three weeks.

Fertilization in mammals is also internal. In this case, however, the egg cells are microscopic, and contain practically no yolk at all. The embryo develops inside the body of the female, and is there nourished. After birth the young mammal is, for a time, suckled by its mother. The number of offspring in mammals is naturally small, but their retention within the body of the female makes it likely that most of them will become adults.

The Significance of Sexual Reproduction.—Sexual reproduction is so marked a feature of organisms that it would seem to have some deep significance. The characteristics of an organism are determined by the nature of the nuclei of the cells of which it is composed. When an organism reproduces vegetatively or asexually there is no change in the nature of the nuclei, and anything bad in the parent as well as anything good is thus perpetuated. Full use of the latter is made by horticulturists in the propagation of varieties of cultivated plants. In sexual reproduction, however, there is a fusion of nuclei, usually from different parents. The resulting organism is therefore a new individual in that its nuclear material is not identical with that of either of its parents. It is thus possible theoretically to combine the good qualities of nearly related plants by means of artificial pollination and nearly all the new varieties of flowers, vegetables and fruit trees have been produced in this way. The new varieties do not always, however, breed true, and use is then made of methods of artificial propagation.

CHAPTER XLIV

GERMINATION AND GROWTH

A SEED is in some respects comparable to the egg of a bird, in that inside the seed coat is an embryo which will, under suitable conditions, develop into a new organism. Shortly after fertilization (p. 352) a tissue known as the endosperm is formed. Sugars, amino-acids and other soluble food substances enter the endosperm from the parent plant and are there converted into insoluble products. In some cases the food material is stored in the seed leaves or cotyledons of the embryo, and the endosperm does not persist.

Conditions for Germination and Growth.—Seeds will only germinate under certain conditions. In the experiments on respiration described in Chapter XXXIII, it was discovered that moist seeds out of contact with oxygen will not germinate. Oxygen is needed for respiration, which is particularly active in the early stages. Water is also required as a solvent for the stored food materials, as a constituent of new protoplasm and for the maturation of the cells in the root and shoot (p. 243). The carbohydrates, proteins or oil stored up are made soluble by the appropriate enzymes which are present in the seed (p. 259). The soluble products are conducted to the growing points and respired or built up into new protoplasm. When dry seeds are soaked, water is taken up and the seeds swell very considerably. If a glass bottle is filled with dry pea-seeds which are then moistened, the seeds will swell and break the bottle. The third important factor is an adequate temperature, for the speed of chemical reactions is in general roughly doubled for each rise in temperature of 10° C. Thus seeds soaked in icy water will not germinate even if they have been soaked and have access to oxygen. Higher temperatures than 45° C. damage the protoplasm. The ideal temperature varies in the case of different plants. Some seeds need light, others darkness before they can germinate, but most seeds are unaffected

by this factor. Once the seedling has germinated and bears leaves, light is essential for photosynthesis. Light seems to have an inhibiting effect on growth, for if seedlings are kept in the dark for any length of time the rate of growth is relatively greater and they become thin and etiolated.

Germination.—The seed of the broad bean is kidney-shaped and has a tough outer coat called the testa which is crinkled when the seed is dry. The black mark called the hilum marks the point where the seed became detached from its stalk. If the soaked seed is squeezed hard, a little water is forced out through the micropyle which is in this case near the hilum. If the testa is removed, the contents of the seed can readily be divided into two halves each consisting of a structure termed a cotyledon or seed leaf. There is in this case no endosperm. If the cotyledons are dissected carefully apart, the remainder of the embryo comes into view, the shoot or plumule which is very small as yet and tucked away between the cotyledons and the primary root or radicle.

When the seed germinates (Fig. 282), the root grows and bursts the testa near the micropyle. A little later the testa splits open and the plumule makes its appearance from between the cotyledons. The growth of the stalks of the cotyledons helps to free the plumule from the seed. It elongates rapidly owing to the lengthening of the part of the stem above the cotyledons. This part of the stem is at first arched, but after it has appeared above the ground it becomes erect, unfolding the leaves which have developed from the growing point.

As the seedling grows, the cotyledons, which are still inside the seed in its original position below the ground, become smaller and more shrivelled because the food material stored up in them is transferred to the growing regions. It is not until some three weeks have elapsed that the seedling becomes anything like independent.

The seed of the French bean is similar in structure to that of the broad bean. When the seed germinates, however, the root grows out as before, but the cotyledons, with the plumule between them, are withdrawn from the seed itself and carried above ground. This withdrawal does not usually take place until the seed has itself been carried above ground by the rapid growth of the part of the stem below the cotyledons. Germination in which the cotyledons themselves appear above ground and become the first foliage leaves is said to be epigeal. Other seeds which germinate in this way are those of mustard and sunflower, which are non-endospermic,

and castor-oil (Fig. 283), which is endospermic. The acorn, which is a non-endospermic seed, germinates as in peas and the broad bean, the cotyledons remaining below the ground. This method of germination is said to be hypogeal. In monocotyledons, such as

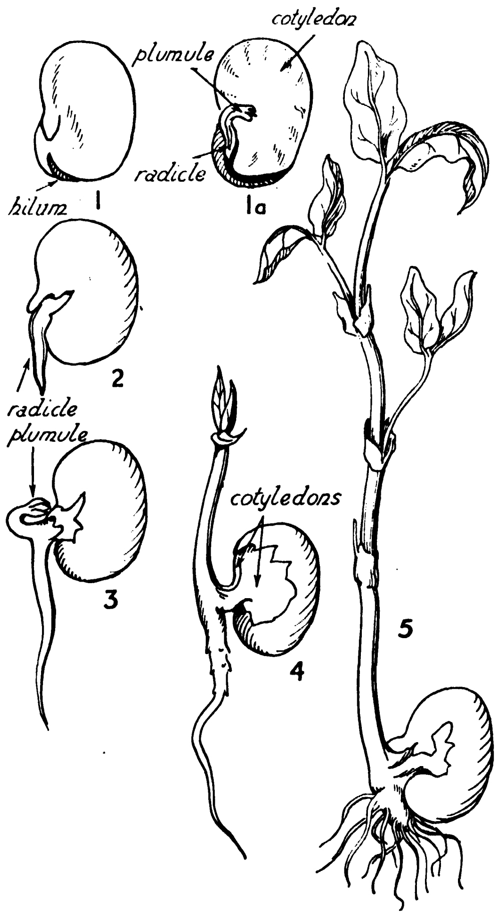


FIG. 282
Germination of broad bean seed

wheat or maize, the bulk of the seed is composed of the endosperm, containing starch with a superficial layer of the protein, glutin. The embryo is restricted to one region of the seed, clearly marked externally (Fig. 199). There is only one cotyledon, which is not in the form of a single leaf at all. Part forms the connexion

between the endosperm and the embryo, termed the scutellum, the other parts forming sheaths which enclose the plumule and radicle. When the seed germinates, these sheaths appear and the shoot and root eventually break through them (Fig. 283).

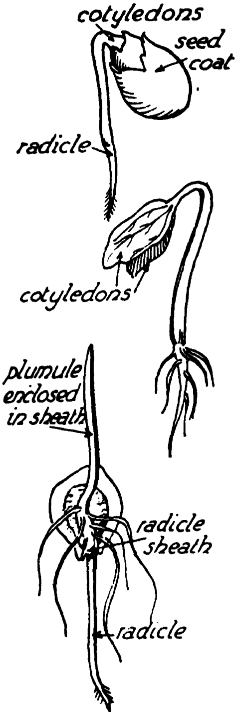


FIG. 283
Two stages in germination of castor oil seed. (Below) Seedling of maize

The germination of a bulb, corm or tuber proceeds along the same general lines as that of a seed. So indeed does the development of any bud. The essential features are the conveyance of soluble food material to the growing point, formation of new protoplasm, cell division and the elongation and differentiation of cells. A favourable temperature, free oxygen, and water are just as essential for the growth of buds and bulbs as for the germination of seeds.

Measurement of Growth.—It is frequently desirable to be able to measure the amount by which a plant has grown in a given time as, for example, in determining the effect of various temperatures upon growth. In the case of a root, the seed may be pinned to a piece of cork, and the latter fixed at the top of a tall jar, containing water, in such a way that the root can grow downwards. By means of horizontal marks on the glass, or, better still, on the root itself, the growth of the latter may be easily determined. In making marks on the root care must be taken that no injury is inflicted, and it has been found convenient to make these marks by means of a thread soaked in Indian ink. The thread is tied to the ends of a curved glass rod, and is drawn across the root. The distribution of the marks after a few days will also serve to show very clearly that the elongating region of the root is the tip. The marks here will be found to be farther apart than when first made, and no change will be made farther back.

The measurement of the growth of the stem is more difficult. In the early stages, it could be done by the same means as with the young root, but the tip is, of course, not visible in the same

way since it is covered by leaves. Plant tissue does not often grow so rapidly as to be visible to the naked eye, and various methods have been adopted to make it visible. The growth of certain parts of plants can often be seen under the microscope over fairly short periods of time, but the method usually adopted is to find some means of magnifying the true growth. This method depends upon the attachment to the tip of a growing shoot of a piece of thread by means of a knot, which is attached at its other end to a light pointer, pivoted so that the far end of the pointer describes a wide arc compared with the distance the near end is pushed up by the growth of the tip. The success of the method depends upon the freedom of the pivot and on the efficiency of the knot tied to the tip of the shoot. Many refinements are possible. The apparatus usually used for accurate work depends on the same principle, with the exception that the far end of the pointer records its movement on a smoked paper wound round a slowly revolving drum. Such an apparatus is termed an auxanometer.

The natural way in which to express results is by means of a graph, in which one ordinate represents the actual growth recorded, and the other the times involved. As might be expected, such a graph shows that the tremendous activity in a germinating seed is reflected in a period of very rapid growth after the latent period, in which the seed's resources were being organized. Such activity cannot persist, and, after a period which varies in different organisms, the rate of growth falls until it becomes stationary, and finally does not progress beyond the amount required to replace ordinary wear and tear. A curve constructed in the same way to show the increase in weight in a germinating seed would not by any means follow the same course, since, in the matter of food material, the seed, for a considerable time, lives upon its capital. This is rapidly used for respiratory and other purposes and consequently the weight of a germinating seed steadily decreases.

Factors influencing the Direction of Plant Growth.—(*a*) *Light*. When plants are kept in any situation in which light only reaches them from one side, a very marked bending towards that side is soon observed. The matter may be investigated experimentally by putting some seedlings in a plant pot inside a cardboard box, into which light is admitted only through a hole cut in one side of the box. The stems bend over towards the light in a very few days. The stem does not merely bend, but grows

towards the light because the rate of growth on the side of the plant away from the light is relatively greater than that on the nearer side. When oat seedlings, from which the tips of the shoots have been removed, are exposed to unequal illumination, there is no bending movement for a few days until a new tip has been formed. It is clear that the tip both perceives and responds to the stimulus. The information gained from a study of the growth substances termed auxins has given some clue to the mechanism of the response. When the tip of the shoot of a decapitated oat seedling is put on to a thin piece of suitable jelly, the latter becomes impregnated with the growth substance. If a piece of this jelly is applied to one side of a decapitated oat seedling it causes a bending movement of the latter away from the side on which the jelly is applied. The bending has been shown to be due to the elongation of the cells of the side to which the jelly has been applied, showing that the effect of unequal illumination must cause an unequal distribution of auxin. A stem grows upwards partly because it responds positively to the stimulus of light, that is towards the stimulus. It can be shown by illuminating unequally the root of a seedling in the apparatus used for measuring its growth in length that, with very few exceptions, light has no effect on the direction of growth of roots. Leaves grow at right angles to a source of light. As sunlight is so essential for photosynthesis, the bending movement of the stem and leaves is very much to the advantage of the plant.

(*b*) *Gravity.* If light does not affect the direction of growth of roots it is possible that gravity might be responsible for their growth into the soil. If a germinating broad bean seed is pinned to a piece of cardboard so that the root or shoot is growing horizontally, the direction of growth will soon be changed, the stem growing upwards and the root downwards, and this will happen whether the experiment is carried out in the light or dark. If the tip of the root or shoot is cut off, response is delayed until a new tip has been formed. The mechanism of this response is of much the same nature as in the response to light, in that gravity causes an unequal distribution of auxin in the tip of the root and shoot, and that the bending is due to increased growth on the side which has the most auxin. The effect of gravity may be neutralized by slowly rotating a root or stem placed horizontally so that each part of the organ in question comes under the influence of the stimulus for an equal period. The experiment must, of course, be

carried out in the dark to prevent any complications due to the effect of light. The apparatus used is a piece of clockwork called a klinostat (Fig. 284), specially designed to hold a plant pot or similar receptacle horizontally. The klinostat may also be used to rotate a plant vertically in order to neutralize the effect of one-sided illumination.

(*c*) *Water*. The function of roots is to absorb water, and it is common knowledge that they branch very freely and grow for long distances in search of it. One might therefore expect water to play a considerable part in determining the direction of growth of a root. This is shown by the growth of roots direct into water in several previous experiments in which seeds in a muslin bag, or a broad bean seed pinned to a piece of cardboard, have been

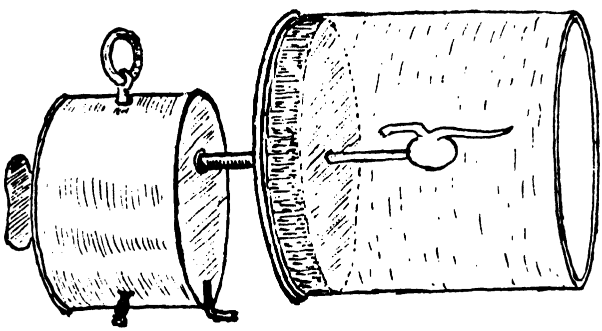


FIG. 284
Klinostat

kept over water. This may, however, have been due to gravity, and a further experiment is necessary to show that the presence of water itself influences the direction of growth. Cress seeds are allowed to germinate in moist sawdust in a piece of muslin tied over a jam-jar containing a quantity of water, and to grow until the roots have reached a considerable length. The muslin and seeds are then removed and placed over a similar jam-jar which contains, not water, but calcium chloride, which has absorbed all the water-vapour from the jar. In a few days, the tips of the roots will turn back and will grow upwards until they reach the moist sawdust, showing that the presence of water affects the direction of growth of a root more than gravity. Again, this tropic response is clearly of great value to the plant. As one might expect, the presence of water has no effect on the direction of growth of stems.

(*d*) *Contact.* Many other types of turning movement brought about by a stimulus of some kind are known, and play important parts in the life histories of many plants. Thus, climbing plants with twining stems or with tendrils are dependent upon the slowing down of growth on the side of the organ in contact with the support so that the organ grows round it. Response to contact is also important in the case of insectivorous plants, such as the Sundew, which respond to the contact of protein-containing substances with their tentacles.

The Growth of Animals.—The essentials of the growth of animal cells are exactly the same as in plants. An adequate diet, containing an adequate supply of vitamins, is essential for the growth of young animals. The transference of food material, formation of new protoplasm and cell division are all concerned, but there is a great difference in that the formation of vacuoles (p. 243) by the absorption of water does not play a part in elongation. Growth in animals is not localized as in plants, but cell division proceeds in all the organs in many different places, with the result that the tissue grows uniformly in all directions. This does not mean to say that growth is unregulated, as the organs have to remain functional the whole time without interfering in the growth or function of any other organ. Regulation is admirably illustrated by the growth of mammalian bones, which have to grow and fit in perfectly with all the other bones, so that movement does not become impossible. Any long bone consists originally of three pieces of cartilage, the shaft and an epiphysis at each end. Separating these three pieces are two regions of actively growing cartilage cells, called growth discs. When the three pieces become bony, the growth discs remain cartilaginous and cell division proceeds rapidly. As fast as the discs grow, the region nearest the shaft becomes converted into bone, which thus grows in length without affecting the joints. The growth of all the bones is regulated by a hormone produced by the anterior part of the pituitary gland (p. 337). The other hormone which plays a prominent part in growth is thyroxine, without which, as has been shown in the frog, the development of the young animal cannot be completed.

The essential conditions for animal growth are, of course, exactly the same as in the case of plants—adequate food material, adequate moisture, free oxygen, and favourable temperature. The two last conditions may be made the subject of experiment as in the case of seeds, using a hen's egg or those of the frog as examples.

If the fertile egg of a hen is painted with varnish, or frog spawn put into water which has been boiled, the eggs will fail to develop. Similarly frog spawn will fail to develop if put into icy water.

Rate of growth is not here so much rate of increase in length, though that can be measured, as rate of growth in all directions. Increase in weight is usually taken to be the best index of rate of growth, and this can readily be carried out with any small animal, provided that the measurements are begun sufficiently early to include the early " grand " period of growth. Maggots, worms, guinea-pigs, mice may all be used for this purpose. A graph obtained in this way should be compared with the graph obtained with plant growth. A hen's egg steadily loses weight during the incubation period because, as in a seedling, respiration is active and the food is being used up and not replaced.

Living and Non-Living Material.—It is now convenient to say something of the differences between living and non-living matter. A living organism both moves and grows. These activities are known in the inorganic world, since some machines move and crystals " grow " under certain conditions. It is true, however, that the movement of machines and the growth of crystals are of a different nature to the movement and growth of the organism. It is instructive to compare a living organism to a piece of machinery, such as a steam or internal-combustion engine, with which it has something in common. For instance, they both need fuel, oxidize fuel and produce various waste materials. The chief difference here is that oxidation in the organism is a less violent and more continuous process. The fuel, of course, is of a different nature, but one of the ways in which the liberated energy appears is in movement. Both are irritable in that they respond to stimuli, the engine in one definite way to one definite stimulus, the organism to many stimuli, not necessarily always to the same extent or even in the same way. Both are automatic in the sense that, once started and given sufficient fuel, they function unaided for long periods.

One primary difference lies in the fact that the fuel in the engine is not assimilated and built up into the material of which the engine is composed, as happens in organisms, which, in consequence, grow and later reproduce their kind, both activities being unknown among engines! The development, self-regulation and differentiation of the organism and the fact that all its numerous activities are directed towards its own benefit distinguish the organism from all machines. Nor does the organism have to be started up!

It is clear that it is not easy to define exactly what is meant by the word life. The phenomena enumerated above are characteristic of ourselves, of Amœba and of all other living organisms, and are external signs of the activities going on in the protoplasm itself. Something is known of the chemical nature of protoplasm, and also something of its physical constitution, but it has never been synthesized, and success in this direction is improbable.

CHAPTER XLV

THE BALANCE OF NATURE

FOR the purposes of study, the vegetation of the countryside is divided into large units, such as woods, marshes, heaths and chalk downs. These units are known as plant associations. In the damp oak wood, which is common on heavy clay, the most important plant is, naturally, the oak, though there may be a few other trees. In all woods a very characteristic feature is that there are several distinct layers of plants, enabling them all to get an adequate share of the sunlight and air available. The layer beneath the trees consists, in this case of shrubs such as hawthorns, brambles, honeysuckle and so on, while underneath this are smaller herbaceous plants. Many of these, such as anemones, bluebells and primroses, flower in the spring before the oak leaves cut off some of the sunlight. Later in the year the ground flora is very well represented because the oak leaves do not form a very complete barrier to the sunlight. The lowest layer of all is composed of mosses, which can do with very little in the way of light, but are very abundant in the damp conditions.

As far as the animals are concerned, there is much more variety. There are many more kinds than of plants, and many of them are exceedingly small. All of them, however, are dependent ultimately on the plants for their food, and every plant, every nook and cranny, will be the refuge of a large number of animals. The soil will contain large numbers of worms of various kinds, many insects and insect larvæ, centipedes, millipedes and so on, in addition to innumerable smaller organisms. On the surface of the ground and often inside all the plants will be hosts of different kinds of insects and insect larvæ, together with such animals as spiders. Feeding either directly on the plants or on the insects will be the birds and mammals of various kinds, some small such as mice, others large such as foxes. The whole forms a typical association with characteristics peculiar to it, and one

would expect to find it wherever there is an adequate area of clay in this country.

Factors determining the Nature of Associations.—(*a*) *Soil and Climate.* The distribution of plants is greatly affected by local conditions. One of the primary factors is the nature of the soil. Thus, the typical vegetation of the heavy clay of the Weald is the damp oak wood, as opposed to the beech wood found on the chalk of the South Downs. In Surrey, where the soil is very sandy, pines and birches are the chief trees to be found. Many other conditions affect plants, such as the local climate, including such factors as temperature and rainfall. For instance, the climate of this country is very different from that of the tropics, where the extreme heat and abundant moisture provide the best possible conditions for plant growth. Altitude, exposure to the wind, slope and many other features are further factors which must be taken into consideration. Thus, the plants to be found in the upper rocky regions of the Welsh, Scottish and Lakeland hills are very different from those found in less exposed places. The distribution of animals is largely dependent upon the distribution of plants, and is therefore primarily determined by the factors mentioned above.

(*b*) *Competition and Adaptation.* The world is simply teeming with animal and plant life. This point may be illustrated by means of a few figures. There are over half a million different species of insects alone, more than all the rest of the animal kingdom put together, and it is hardly necessary to add that many of them, such as midges, are exceedingly numerous. Some fish, such as the cod, are very prolific, each female producing several million eggs. An acre of soil contains tens of thousands of earthworms, and each cubic centimetre several millions of bacteria and protozoa. A ripe mushroom produces several million spores, all of which are capable of growing into fresh mushroom threads. The number of seeds which some of the ordinary garden weeds produce shows why they are so abundant. A single dandelion plant may produce some 5,000 seeds, a single burdock plant over 20,000, and a single poppy plant over 50,000.

These figures show that there must be a great deal of competition between different kinds of organisms, also between different individuals of the same kind. There cannot be sufficient food for all these organisms, and they cannot all survive. Organisms are thus engaged in a twofold struggle for existence, partly against

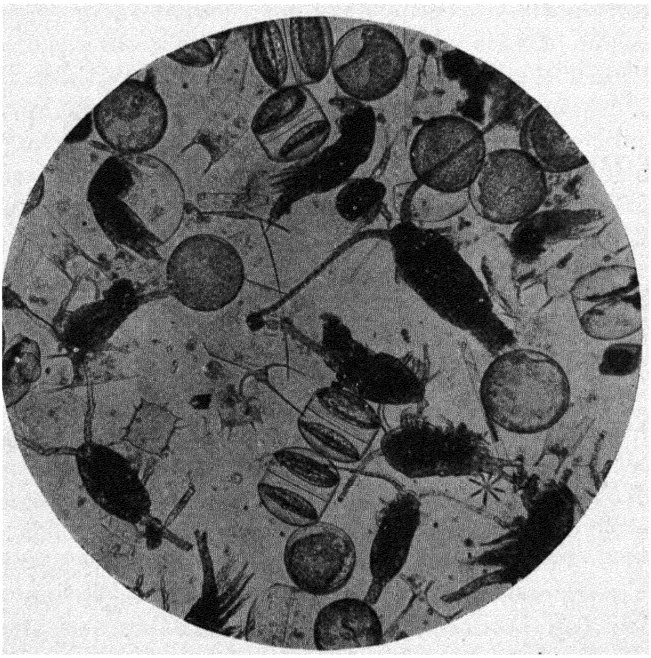
physical and chemical forces, and partly against other organisms. On waste ground competition is particularly fierce, but in time such an area will pass into a stable association in which competition has become less intense.

Although individual animals and plants are frequently studied in the laboratory, this is merely a matter of convenience. The organism can never be accurately studied apart from its surroundings: it is always a member of an association or a community of organisms and its structure and habits are the result of a long history under these conditions. In short, the organism is adapted to its environment. A good example of such adaptation is a small community consisting of bracken, bluebell and soft grass found in damp oak woods. These plants tap different layers of soil and reach their maximum development at different times.

Relationships between Organisms.—(*a*) *Food Chains.* It has been implied in a previous chapter that, as all carnivorous animals are dependent in the long run on herbivorous animals, it is merely one step further to say that animals are absolutely dependent upon plants for their food, and could not exist without them. In the case of our own food, cereals (and consequently flour), fruit and vegetables are all products of plants themselves, while beef, mutton, pork and ham are all provided by animals which feed directly on plant materials. Mushrooms are plants which derive their food from decaying plant remains; eggs are provided by hens which feed on grain; honey by bees which obtain the nectar from flowers; and so on. Beer is a solution of various substances, all produced by plants of one kind or another, the sugar from barley, and other substance from hops.

We are not usually eaten by other animals, but such is the common fate of many other creatures, and so the food chain, as it is called, may be extended. In a garden, for instance, green-fly and similar bugs suck juices from plants and may be eaten by a ladybird which may, in its turn, be eaten by a spider or by a bird. If all the possibilities are included, a food chain becomes very complicated indeed. In fresh water and the sea the basis of all life is the plants in the plankton (Fig. 285), which is the name given to the drifting microscopic organisms in the surface layers. Some fish and smaller animals in the plankton, such as water fleas and similar organisms, feed on these plants and they, in turn, are eaten by fish. In the sea, the system is more complicated, since there are more smallish animals which form intermediaries. Thus,

barnacles feed on plankton brought to them as the tide rises, and they are preyed upon by carnivorous molluscs, such as the dog whelk. Bivalve molluscs such as oysters, mussels and cockles feed on plankton and are themselves eaten by starfish, whelks and fish. Thus, all animal food is dependent ultimately upon green plants, which are themselves independent of any organic food. Their " diet " consists of very simple substances indeed—carbon



Courtesy of D. P. Wilson, Marine Biological Laboratory, Plymouth

FIG. 285

Summer Plankton (marine) seen through the microscope, showing diatoms and microscopic crustaceans

dioxide from the air, water and inorganic salts from the soil. These substances are built up into sugars by a complicated process, the necessary energy being supplied by the utilization of the energy absorbed by chlorophyll from sunlight. Thus, all our food and the food of all animals is ultimately dependent upon the energy of the sun. Food chains may thus be rewritten as energy chains, the energy of sunlight being converted into the chemical energy of sugars and other organic compounds in plants. Animals are dependent upon the chemical energy contained in these organic

compounds which, as in plants, can be converted into other forms of energy by combustion. A somewhat similar chain can be built up in the case of the steam engine. The chemical energy is here contained in coal, which consists of the fossilized remains of green plants, which in turn derived their energy from the energy of sunlight by photosynthesis. The energy contained in the coal is, of course, released by combustion, and heat energy is set free.

(*b*) *Parasites.* Parasites withdraw soluble organic compounds from a living "host." The most widely distributed of all parasites are probably the bacteria, many of which cause diseases in plants

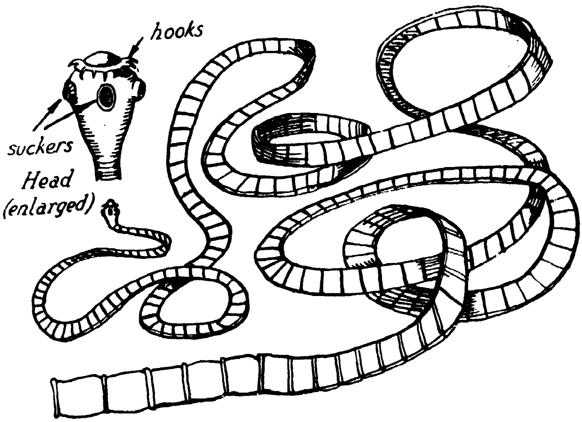


FIG. 286
Tapeworm

and animals. The life of an internal parasite is, as might be supposed, a very specialized form of existence, and leads to radical changes in structure and function in this type of organism. A very good example, which illustrates these points, is the tapeworm (Fig. 286), various kinds of which live in the intestine of mammals. The first kind of adaptation is the simplification of such structures as the muscles which, as the animal does not move about, are not needed to any great extent. The tapeworm lives in an environment in which there is a continuous supply of digested food which is absorbed all over the surface of its body, the intestine and mouth having disappeared. It also possesses various new structures adapted to its parasitic mode of life, such as the ring of suckers and hooks on the tiny head, which enable it to retain its

hold. Further drastic modifications are seen in the life history, which becomes extremely complicated, since the odds on a single egg reaching another host of the same kind are exceedingly remote. Consequently, most parasites produce an enormous number of eggs, only a few of which ever reach the adult stage. Chance plays a large part in the distribution of the eggs of parasites. Very frequently the parasite spends part of its life history in another totally different kind of host before reaching the original kind once again. There must, of course, be some connexion between the two different kinds of host. In the case of the malarial parasite, described in a previous chapter, the two hosts are man and the mosquito, the connexion between them being obvious. In the case of the tapeworm, the two hosts are man and the pig, and the parasite is dependent firstly upon a pig eating food contaminated with eggs voided from the intestines of the other host, and secondly upon a man eating pork which contains the parasite. Meat inspection and modern methods of sanitation minimize any danger of infection by this parasite.

Not all parasites have become modified to anything like the extent found in the tapeworm. Many, such as the mosquito, flea, and green-fly, are external parasites, and the sucking apparatus is the only parasitic modification, apart from the loss of the wings in the flea. In plants, the fungi are by far the most important group of parasites, the fungal hyphæ entering plants through stomata, or wounds, or in various other ways, and living at the expense of the host plant. There are a few parasitic flowering plants, notably the dodder, which illustrate the same general principles with regard to plants as did the tapeworm in the case of animals. This plant, which coils round clover and other stems, is a degenerate relative of the convolvulus devoid of chlorophyll, and exhibits many parasitic features. Its structure is simplified, it produces special structures which grow into the veins of the host plant and extract food material, and it has clusters of tiny red flowers which produce an enormous number of minute seeds. The mistletoe is a parasite which has retained its chlorophyll and obtains some of its food by photosynthesis.

(*c*) *Saprophytes*. The majority of the bacteria and fungi absorb soluble organic materials from decaying organic material. Fungi are thus common in autumn when the leaves of trees are falling and beginning to decay. Some of them, especially those which are brightly coloured, are very poisonous. Among flowering plants

a few orchids have lost their chlorophyll and become completely saprophytic, absorbing soluble organic compounds from the soil.

(*d*) *Insectivorous Plants.* A few flowering plants found on damp heaths and similar places which tend to be deficient in nitrates add to their supply by retaining and digesting the bodies of insects which happen to alight on them. The leaves of the sundew are provided with "tentacles," which bend over the insect and prevent its escape. Glands produce a digestive fluid which is poured over the body of the insect, and the soluble compounds so formed are absorbed. Other British examples are the bladderwort, an aquatic plant which traps and digests water fleas in small bladders, and the butterwort with sticky leaves which tend to roll up longitudinally, in this way retaining and digesting insects which have alighted on them.

Death and Decay.—The first stage of decay in any organism is that the enzymes are no longer subject to control, and they act on the carbohydrates and proteins of the protoplasm, producing various soluble compounds which are washed away into the soil. The more resistant parts of an organism, such as bones and teeth, resist decay for a long period, but the soft parts disappear in this way very quickly. The nitrogenous and other compounds so formed constitute the material from which certain groups of saprophytic bacteria obtain the energy with which to build up carbon dioxide and water into sugars, and also to build up new protoplasm. The building up of sugars in this way resembles photosynthesis, except that the energy involved is obtained from a chemical reaction instead of from sunlight and is consequently termed chemosynthesis. The chemical reaction which provides the energy is a form of respiration, and is in some cases aerobic, in others anaerobic.

The amino-acids formed in decay are made use of by bacteria belonging to the genus Pseudomonas, energy being set free and ammonia formed as a by-product. The ammonia is utilized in a similar way by Nitrosomonas and other bacteria, nitrites being formed as waste products. The nitrites are oxidized to nitrates by Nitrobacter. In this way, the amino-acids set free into the soil by decay are gradually converted by these nitrifying bacteria into the only form in which nitrogenous compounds can be absorbed by green plants, namely nitrates (Fig. 287). This, however, is not the end of the story, as in bad soils denitrifying bacteria are present, which obtain their energy by setting free nitrogen from nitrates, thereby diminish-

ing the supply of the latter. There are in all soils nitrogen-fixing bacteria which obtain their energy by turning atmospheric nitrogen into nitrates, thereby increasing the supply of the latter in the soil. Thus, even if no decaying material is ploughed into a piece of land which is allowed to be fallow, nitrates will be formed in it slowly by these nitrogen-fixing bacteria. There is yet a further

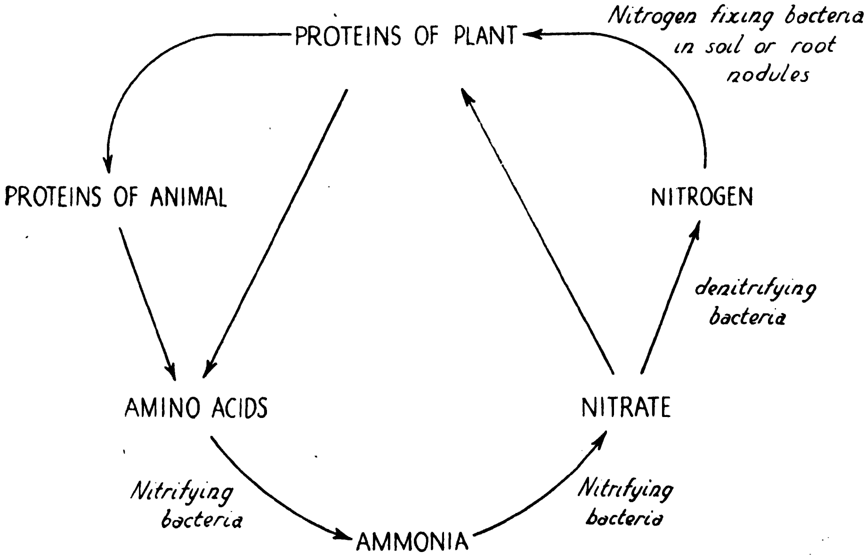


FIG. 287

Circulation of nitrogen in nature

important point to be considered. One kind of these nitrogen-fixing bacteria finds its way into the roots of one particular family of flowering plants—that including peas, beans, lupins and clover. The region of the root affected swells and forms a " nodule." The bacteria thus obtains shelter from the plant, while the latter in some way acquires a share of the nitrates formed by the bacteria.

Rotation of Crops.—These facts are utilized in the systematic planning of crop production. The old system of allowing ground to lie fallow every fourth year is very wasteful, as it means that a quarter of the acreage is lying idle every year. On the other hand, crop production drains the soil of salts very considerably and these must be replaced by the application of stable manure which consists of decaying organic material, or by artificial manures which consist of individual salts such as ammonium sulphate, or potassium

nitrate. Artificial manure is, however, quite expensive. The system of rotation of crops is merely the application of knowledge of a few simple facts about the crops concerned. The roots of wheat are extensive and extract salts from both deep and superficial layers of soil. A root crop, such as turnips or mangolds, should follow, as it taps the middle layer and allows the upper layer to recover by bacterial action. In the third year, oats may be grown, as this crop has superficial roots and allows the deeper layers to recover. In the fourth year, clover or a similar crop should be grown and, in this case, the roots, which bear nodules, are ploughed in, leaving the deep layers comparatively rich in nitrogen for the wheat which is to follow in the next year. Such a system, the general principles of which were practised in Roman times, ensures that the ground shall be used to its greatest advantage.

CHAPTER XLVI

PONDS AND STREAMS

PLANTS do not grow in the deepest parts of large lakes because light does not penetrate to a sufficient depth for them to be able to make starch. In the shallower parts, however, many rooted plants, such as water lilies, water crowfoot and arrowhead, are often found. Freely floating plants, such as the tiny duckweeds, are abundant in stagnant water. The shore of a lake or a pond is particularly interesting because there is usually a gentle slope to the water's edge, and it is possible to see a transition from typical terrestrial to typical aquatic plants rooted in the water. Between these two extremes are such marsh plants as the marsh marigold, rushes and meadowsweet, and plants such as reeds extending farther into the water.

Aquatic plants have many interesting adaptations. The conditions under which they live are more uniform than those on land, and the water is relatively richer in carbon dioxide than air, as this gas is readily soluble. The medium is much denser than air, and thus little mechanical tissue is necessary in plants which are completely submerged. Many rooted plants with aerial stems have large air spaces in their stems and roots. Air enters the internal atmosphere and circulates freely through the plant. The water-logged soil contains no air, and so the roots are unable to obtain oxygen in the ordinary way. The air spaces also make the plant buoyant. Floating leaves such as those of the water lily have a normal upper surface, which is, however, heavily waxed, but the lower surface lacks a cuticle and also stomata. In some cases, as in the water crowfoot, the submerged leaves are quite different from those above the surface of the water, being finely dissected and thus presenting a large amount of surface to the water. Many floating plants have a poorly developed root system, and may as in bladderwort have no roots at all.

Plankton.—Plankton is caught by means of a special kind of

net of very fine mesh, which is drawn through the water, either from a boat or from the bank, so that the organisms present in a large volume of water remain in the jar tied to the end of the net.

The diatoms which form the basis of life in the pond are very small, and a net of extremely fine mesh is necessary to capture them. In stagnant water weeds become encrusted with comparatively large brown diatoms which can readily be examined under the microscope. The most obvious animals in the plankton are the water fleas (Fig. 288) which have a large compound eye and

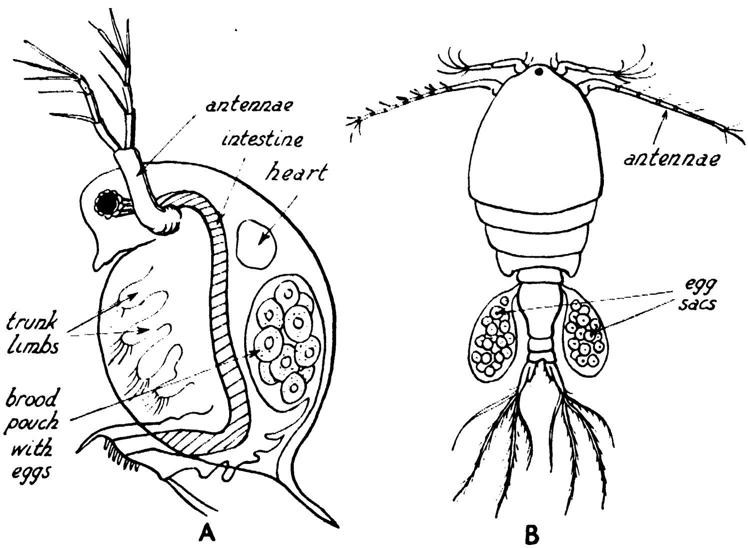


FIG. 288

A. Water flea (Daphnia). B. Cyclops

swim by means of their antennæ. They may be recognized by the two valved backward projections from the external skeleton of the head, which completely enclose the very short body. The trunk limbs set up a very vigorous movement in the chamber so formed, and thus create a current of water bringing in small particles of food which are strained off and enter the mouth. It is easy to watch the heart beating, and the food passing along the intestine, particularly if particles of a coloured substance such as carmine or Indian ink have been put into the water. There is a brood pouch at the hind end of the body, often containing eggs. When the animal dies or moults, the eggs remain inside the external skeleton

and are thus protected until they hatch. There are many generations during the year, but males only appear at two definite seasons, in spring and autumn, so that most of the animals grow from unfertilized eggs. This phenomenon is called parthenogenesis, and is fairly common in some animals, particularly insects. An animal related to water fleas is Cyclops (Fig. 288), which is of a quite different shape and considerably smaller. The female usually has two egg sacs attached to her abdomen. Cyclops feeds in quite a different way from the water fleas, the food, which is much the same as before, being seized by the appendages in front and not filtered.

Pond Animals.—Careful search among the plants and in the mud and fallen leaves from the bottom of a pond reveals an unsuspected wealth of animal life. Hydra (p. 391) is frequently encountered, and brown, white and black flatworms are common. At the bottom of muddy ponds are frequently found the vertical mud tubes of a small red worm related to the earth-worm. When undisturbed the tail of the worm projects from the top of the tube in order to obtain more oxygen. The worm feeds on the organic matter in the mud. The so-called fresh-water shrimp and the hog slater are scavengers found practically everywhere. There are, too, a considerable number of water snails of many types. In muddy lakes the large fresh-water mussel is usually found.

Most people, however, find the insect population the most interesting for a variety of reasons. Insects are undoubtedly a terrestrial group, as is shown by the fact that all the aquatic insects retain their tracheal method of breathing in spite of obvious inconveniences. All these insects must have been forced back to the fresh water originally by the pressure of increase in numbers of insects as a whole. It is not just one group which has altered its habits in this way, but a few members of many groups.

The great interest of these insects lies in the various ways in which they have adapted themselves to life in water. Their chief problem, of course, is the modification of their tracheal system so that the tracheæ will not fill up with water, but life in a denser medium must inevitably affect locomotion, feeding habits and life history. Many of the methods involve taking down a supply of air, so that the animal can remain beneath the surface for some little time. In the case of the water-beetle, Dytiscus, the elytra, or wing-cases, form the roof of a chamber into which open the spiracles, and which opens to the exterior at the hind end. Air is

pumped in and out of this by the raising and lowering of the upper body wall. In the water-boatman, on the other hand, a pair of cavities is formed below the body by hair-like structures which project from the side of the body inwards to meet the keel on the under side. In this case, the air is expelled and renewed largely by the rubbing movements of the basal parts of the legs over the hairs, but the latter are capable of being moved in such a way that, when the animal is floating on its back on the surface, the whole cavity can be exposed. The presence of air between the under side of the body and the hairs gives this animal its characteristic silvery appearance, and is responsible for the fact that the animal swims on its back. More ingenious still is the larva of the beetle Donacia, which inserts the hinder part of its body which bears the spiracles into the air spaces of submerged water plants. The spiracles of insects usually have some sort of closing mechanism; in the aquatic forms the openings are usually guarded by means of hairs. Adaptations for locomotion are well seen in the water-boatman, in the stream-lined body and the third pair of legs, which are broad and fringed with hairs. Most of them have modifications along these lines, but there are special cases, such as the whirligig beetles and pond skaters, which are light enough to move about on the surface film.

Aquatic larvæ are very diverse in character, there being as many types as there are groups or, in the case of flies, as there are genera. In some cases, as in the dragonflies and mayflies, the general character of the life history is much the same as in the cockroach in that there is no pupal stage. Mayflies and dragonflies are usually hatched in a comparatively late stage, which lives for two or three years under water before the emergence of the adult. The stage before the emergence of the adult is termed the nymph. Dragonflies are large and extremely beautiful insects, characterized by the bright colours and two pairs of transparent wings with a black spot on the anterior margin of each. They catch their prey on the wing by means of the biting mouth parts which persist throughout life, though in the nymph the labium is enlarged into the formidable structure called the mask. The nymph has a tracheal system, aerated either through the three vertical plates at the hind end of the body, or by the novel method of the conversion of the hind end of the rectum into the branchial basket which contains tracheæ in its wall. Muscles are responsible for alternately enlarging and diminishing its capacity, so sucking water in and forcing it out.

The full-grown nymph crawls up a water weed into the air (Fig. 289), and when dry, the skin splits along the middle of the back, and the dragonfly picks itself out. When the wings are dry, the insect begins its first flight.

The emergence of mayflies is one of the phenomena of the early summer, and one which is eagerly awaited by fishermen, since the flies and the rising nymphs are so greedily sought by fish. The nymphs (Fig. 290) are readily distinguished by means of the three hairy processes arising from the end of the abdomen, but these are not used in respiration as there is a pair of gills with tracheæ

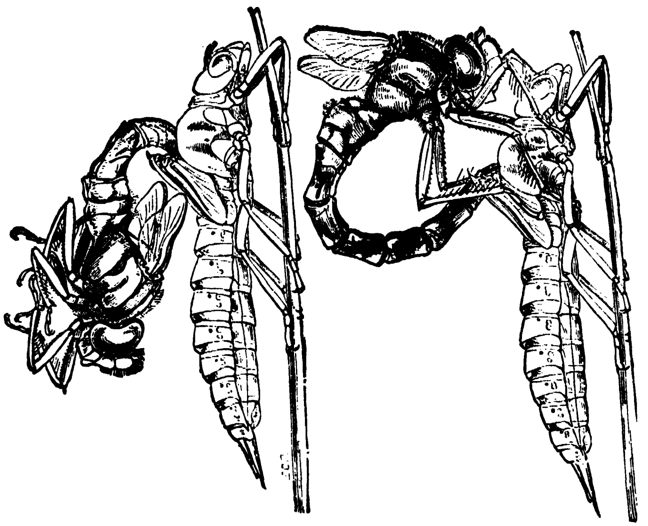


FIG. 289

Emergence of adult dragon fly (Aeschna sp.) from nymphal case

on every abdominal segment. It is probable that these gills represent the abdominal appendages of the insect's ancestors. These nymphs, too, have biting mouth parts and feed vigorously for two or three years. The apparent imago is here not the ultimate stage, for a further moult takes place in an hour or so. The imago does not feed at all and its mouth is not sufficiently differentiated for it to be able to do so. Mating is shortly followed by death; the life of the imago is a matter of only a few hours.

Caddis-flies have aquatic larvæ (Fig. 290) which hatch out to form the egg in a much earlier stage than the nymphs of mayflies or dragonflies, and which pass through a pupal stage. The larvæ

of caddis-flies are unique in that they construct tubes of various materials, such as sand grains, pieces of twigs or leaves, stuck together by their own saliva. The larva lives inside the case, but is strong enough to put out the head and thorax and walk about with it. This mode of life introduces the further problems of fixation to the tube, and also of the creation of a current of fresh water through the tube over the abdominal gills. The former is solved by the presence of a pair of hooked appendages on the abdomen, the latter by the movements of the abdomen.

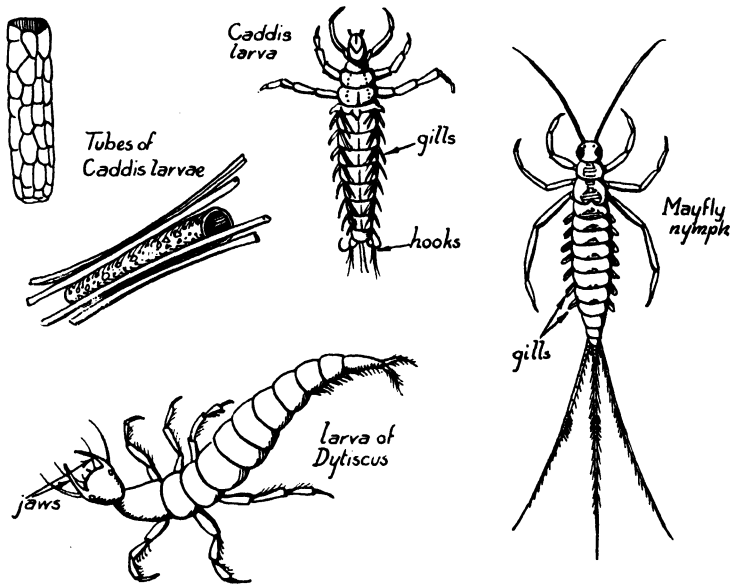


FIG. 290

The larva of the beetle Dytiscus has many interesting adaptations, notably in its methods of feeding and breathing (Fig. 290). The mandibles have, on the inner surface, a groove which conveys the blood from the victim—a tadpole possibly—to the mouth. Both larva and adult are extremely voracious beasts, the latter, for instance, being capable of killing quite large crayfish. The two spiracles open on the tip of the abdomen, and the larva can hang head downwards from the surface film, held by the hairy filaments at the hind end of the abdomen. Fly larvæ are usually very highly modified. Examples are mosquito larvæ and bloodworms (the larvæ of harlequin flies), the blood of which contains hæmoglobin.

Other examples of fly larvæ are the phantom shrimp (larva of Corethra) and the rat-tailed maggot (larva of Eristalis) which has a breathing-tube like a telescope at the hind end of the abdomen.

Streams.—All the above types are common in lakes and ponds, and represent a small fraction of the animals found there. In running water, however, the conditions are very different, since the movement of the water means that unless the organisms can swim quite powerfully or can hang on for dear life, they will be carried away by the stream. Consequently, there are not many planktonic organisms as they would stand very little chance of survival. Some of the larger animals, such as crayfish, hide in holes in the bank, and animals such as worms and burrowing mayfly larvæ burrow in the mud at the bottom. Fish can swim sufficiently powerfully to be independent, and there are, in addition, such mammals as otters and water-voles which enter the water occasionally.

Inlet and outlet streams from lakes have a distinctive fauna depending on the type of bottom and the speed of the stream. In stony streams, most of the animals cling on to the under surface of the stones, e.g. the larvæ of the fly Simulium and a caddis worm, which does not make a tube but hangs on to the stones. The larva of Simulium looks like a small worm, with an expanded base with a sucker by means of which it is attached to stones. The head bears two whirling structures which create a food current. Flat worms, Hydra and colonies of the organisms termed polyzoa may also be present.

CHAPTER XLVII

ADAPTATIONS AND LIFE HISTORIES OF FISH, FROGS AND BIRDS

FISH have become extremely well adapted to life in water. They move very swiftly through the water, the streamlined body being propelled by side to side movement of the tail, which consists of little else but solid muscle and bone. The unpaired fins keep the fish on an even keel, and the paired fins, which correspond to the limbs of other vertebrates, are used for changing level. In addition to eyes and smelling organs, the fish has an elaborate system of sense organs contained in what is known as the lateral line, a canal opening to the exterior at intervals. These organs detect vibrations in the water, and the ear must be regarded as an enlarged and specialized part of this system. Scales, too, are characteristic of fish, forming a protective layer over the body wall. The only part of the latter which is permeable to water and dissolved substances is the wall of the gills. Water, except in the shark group, enters at the mouth, and flows over the gills, emerging from behind the operculum. In the shark group, the water enters through a passage, termed the spiracle, immediately behind the eye. In this case, there is no operculum, and the gill slits are visible externally.

Fertilization in fish is normally external, the eggs, often laid in enormous numbers as in the cod, being either planktonic or in some cases, as in the herring, deposited on the sea floor. " Soft roes " of fish are the testes, " hard roes " the ovaries in which each sphere is a single egg. Dogfish and skates, in which fertilization is internal, lay a small number of large yolky eggs, each of which is enclosed in a horny " mermaid's purse." Life histories show a great deal of diversity. Some of them, such as those of the salmon and the eel, being very remarkable indeed. In fresh water the life history is usually simple. For instance, the pike lays among the weeds about half a million eggs which hatch in about three weeks.

Fish eggs are transparent and the embryo is clearly visible within. The stage after hatching, in which the yolk has still not been completely absorbed into the embryo, is also characteristic of fish. The development into the adult fish from this stage is uneventful in one sense, though in another sense the vast majority of the larvæ will be eaten by other animals. The males of the ordinary stickleback become bright red in the breeding season, and construct a nest with pieces of weed. They defend the eggs with great ferocity. Herring, which are not found in shoals at other times of the year, move in-shore to breed, and appear in great numbers round various parts of our coasts throughout the summer.

Life History of the Salmon.—It is probable that in the past there were many more salmon streams than there are now, when so many have been polluted by industrial processes. The striking feature of the life history is the ascent of the fish from the sea to the upper reaches of the stream in which it began its own existence. Some Pacific salmon ascend the Yukon for well over 2,000 miles for this purpose. The ascent involves many difficulties, one of which is the negotiation of any waterfalls which bar the way to further progress. The fish is capable of leaping out of the water over obstacles of this nature up to a maximum of some ten feet, a very striking and beautiful sight. In some places, particularly where salmon fishing is an economic proposition, " ladders " have been provided in order to make possible the ascent of formidable heights. When the fish leave the sea, they are in very good condition, but for some reason they feed very little, if at all, in fresh water. After the efforts of ascending the river and breeding it is not surprising that their condition rapidly deteriorates until they reach the sea again many months later.

Breeding actually takes place in the autumn, though the ascent may be completed earlier in the year, and several weeks spent in the upper reaches before the time is ripe. The male develops a hooked lower jaw during this period, with which it scoops out a shallow depression called a " redd," in which the female lays a few thousand comparatively large yolky eggs, over which the milt of the male containing the spermatozoa is poured. A single pair may dig several trenches in a single season involving up to 30,000 eggs. The trench is covered up by brushing movements of the tail, sufficiently loosely to permit adequate aeration. Subsequently the parents begin their journey down to the sea again, much exhausted and now much easier prey for such animals as otters.

The young hatch out early in the following year from the eggs which have survived, something like 90 per cent. of them having been killed by adverse conditions or by various enemies. The alevins, as they are called, pass through an embryonic stage with a yolk sac, but they soon become sufficiently active to hunt for their own food and incidentally to be hunted by other fish (Fig. 291). They are now called parr, and can be distinguished by a series of bluish bands crossing the lateral line. After about two years from the time of hatching, they begin to move in shoals downstream towards the sea, and are now termed smolts. It is

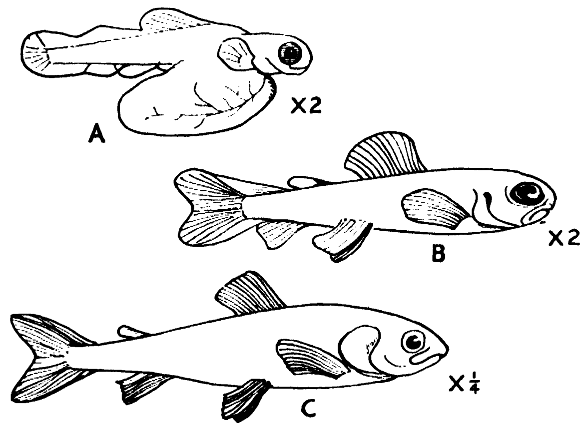


FIG. 291

Life history of Salmon. A—Fry immediately after hatching. B—Fry one year old. C—Smolt

(After Roule. "Fishes," published by Messrs. Routledge & Sons Ltd.)

possible, as with other migratory animals, to discover something of their movements by marking, though the results are not as satisfactory as could be desired. They feed on mackerel, and probably do not move far from the shore, but the details of their movements are not definitely known. It can be proved by marking that the young salmon, now termed grilse, which ascend the streams in subsequent years have previously descended the same stream. Grilse are large fish weighing several pounds, probably too big an increase from the smolt for this change to have happened in a single summer, though this has sometimes been claimed.

Life History of the Eel.—The eel is a fresh-water fish which goes to the sea to breed, and it is only comparatively recently that the details have been known. It has, of course, been known for a

long time that eels descend our streams in great numbers every autumn, but marking is of no use in this case, since the eels never return. It is the young eels called elvers which return and ascend again the following spring. Obstacles in the rivers present less difficulty to eels than to salmon, since they move by the wriggling movements of their long wormlike bodies, and can actually migrate over land. They do this chiefly under moist conditions at night,

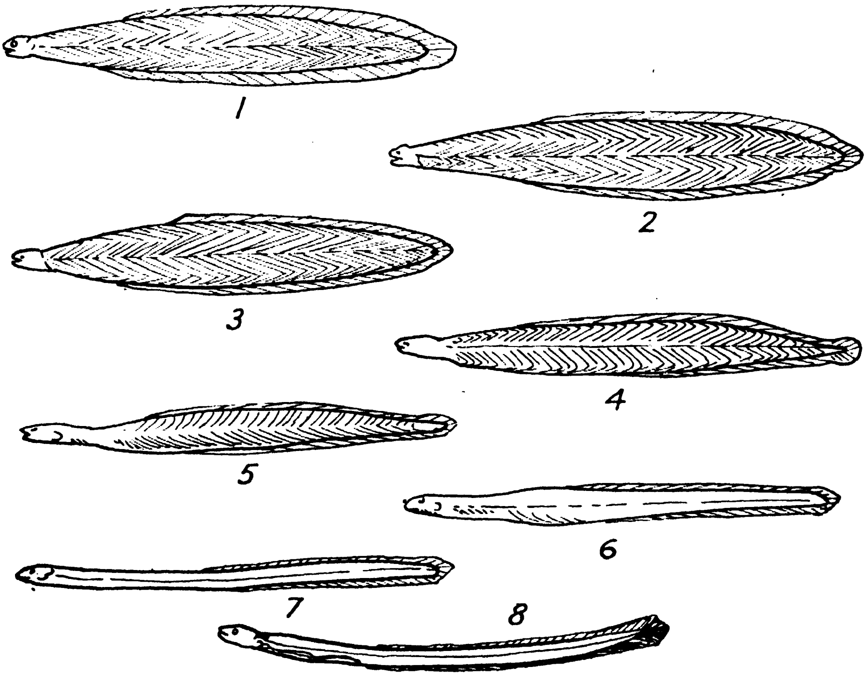


FIG. 292
Life history of eel

their gills being pouch-like and able to retain sufficient water for quite long journeys on land. American elvers have made their way round Niagara Falls!

The full story of the eel has been discovered by Danish investigators by tracing the movements of the elvers backwards across the Atlantic. Once the connexion between the elvers and the tiny creatures previously known by the scientific name of Leptocephalus had been established, the distribution of the latter provided the key. They are transparent leaflike creatures (Fig. 292) with a small head and black eyes, which swim vertically in

the surface waters. From hauls near the coasts of Western Europe and at intervals right across the Atlantic, these Leptocephali were found to become gradually smaller, and to be at their smallest in the waters south-east of Bermuda. The explanation is that the mature eels cross the Atlantic from east to west and breed at depths of nearly 2,000 feet. The offspring spend about a year in their birthplace, ascend to the surface when about an inch long, and set off on the journey back across the Atlantic, presumably to the stream which was the home of their parents. This return journey is greatly assisted by the warm Gulf Stream, but it takes three years so that the elvers on their arrival are four years old. It is strange that American eels also breed in much the same place, slightly to the south-west.

Amphibia.—Examples of this class of vertebrate animals are frogs, toads, newts, and salamanders. They have legs instead of fins and breathe by means of lungs. The skin has no scales of any kind and is sufficiently thin and moist for a good deal of the oxygen which enters the body of a frog to do so through the skin. They are thus in most cases amphibious creatures, which always breed in water if they do not frequent it at other times. Newts use their tails for swimming, but frogs, though their hind feet are webbed, have lost their tail entirely and are very specialized for jumping. Two of the ankle bones have become very long for this purpose. Amphibia usually eat insects and other small animals which are whisked into the mouth by a lightning movement of the tongue. Amphibia nearly always have a tadpole larva, as in the frog.

Life History of the Frog.—Frogs, being cold-blooded, hibernate during the winter and reappear in great numbers towards the end of March, croaking vigorously. The frogs mate almost immediately, and frog spawn becomes very abundant in ponds and ditches. The lower part of the egg contains yolk which provides food material for the embryo until it hatches, three weeks after fertilization. The first division cleaves the egg vertically into two halves, the second division, also vertical, is at right angles to the first, and the third is horizontal. The cells of the lower tier each contain a good deal of yolk and are consequently larger than those of the upper tier. Cleavage is much more difficult through the rather dense yolk than through the black end of the egg, and the division on the latter part is faster, with the result that the black cells grow round the yolk and enclose it with the exception of a small pore.

Various protuberances now begin to arise (Fig. 293), the tail growing out backwards from just above the anus, while on the head the eyes and nostrils become visible, also the rudiments of external gills and the " sucker " below the mouth. The young tadpoles now hatch and hold on to water weeds by means of their " suckers." They are herbivorous at first, feeding on water weeds, but some time later change over to a carnivorous diet, a change which leads to a relative shortening of the intestine since animal material is less difficult to digest.

The tadpole swims by means of its tail, breathing by means of three pairs of feathery gills on each side. These do not last for more than a week and are replaced by a corresponding number of internal gills exactly like those of a fish, water flowing in through the mouth and out again through the gill-slits, the gills thus being supplied with fresh water. This stage is in all essentials very fish-like, even to the possession of the special sense organs of the lateral line, which are otherwise peculiar to fish. A fold termed the operculum now grows backwards from the head, covering the gills except for a pore on the left side. The gills remain functional, the water from all the slits escaping through the pore. The tadpole spends several weeks in this condition with little apparent external change. The front limb buds have begun to form, but are as yet concealed by the operculum so that the hind limb buds actually become visible first. Eventually the front limbs do appear, that on the right side coming through the operculum, that on the left through the pore previously mentioned.

After three months or so, the exact time depending on the conditions under which the tadpole has been developing, changes begin to happen much more quickly. The legs reach a stage in which they are capable of being used on land, and the young frog leaves the water, being now about one inch long. The lungs, which have been slowly developing, now come into use and the tail, which is no longer useful, begins to be rapidly absorbed. Tadpoles in aquaria require plenty of food, including such material as lean meat and pieces of egg if they are to metamorphose completely. It has also been shown that the process will not be completed if the thyroid gland is removed from the tadpole, and will actually be accelerated if thyroid extract is fed to it. This is quite easy to do experimentally, several groups of tadpoles of the same age being fed with graded doses of extract, one group being kept as a control. Tadpoles which are given large doses show symptoms of

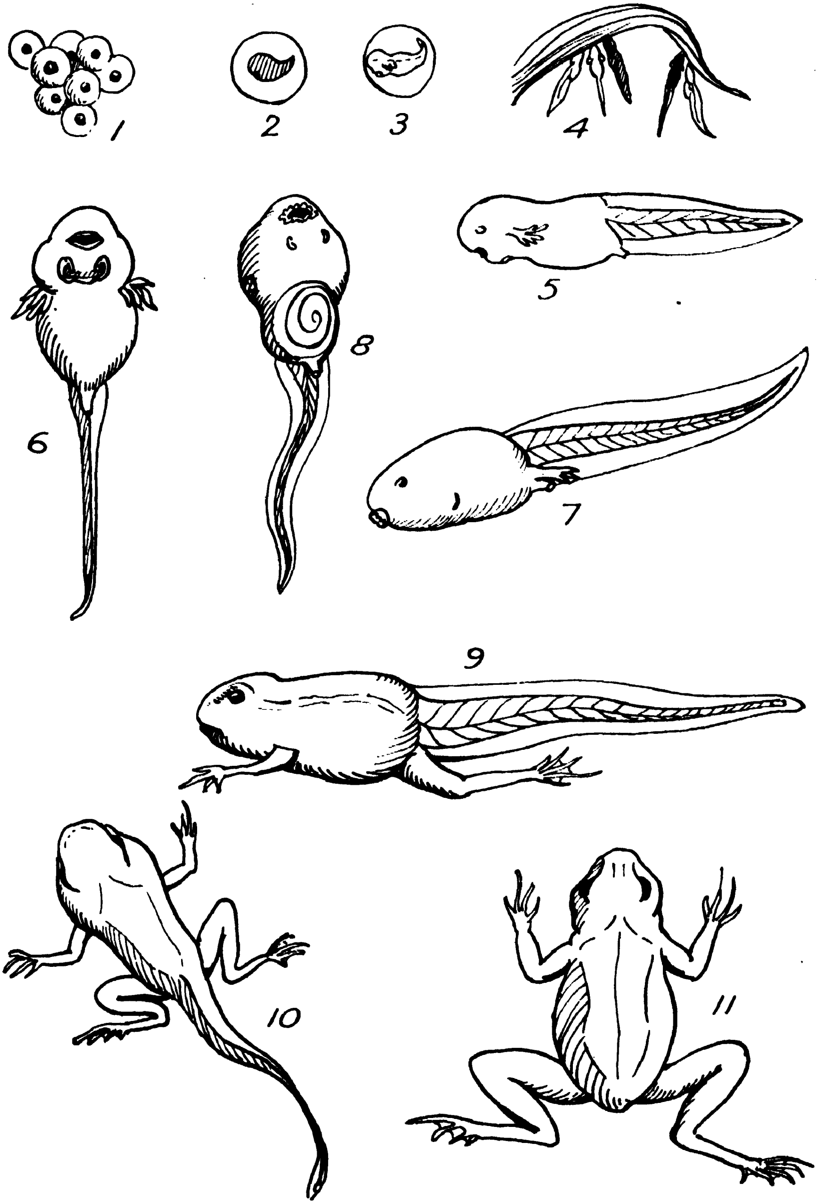


FIG. 293
Life history of frog

a human disease associated with the production of too much thyroxin by the thyroid gland.

Adaptations of Birds for Flight.—Birds are beautifully streamlined, the centre of gravity being low, and projecting structures such as the legs being tucked away in actual flight. There are no teeth, the jaws being elongated and covered by a horny beak. The eyes are large and have some features peculiar to birds, but there is no external ear, which is an exclusively mammalian production. Feathers are peculiar to birds, and play a most important part in flight. They also form an insulating layer which prevents the escape of heat from the body. The feathers are comparable to the hairs of mammals, and they arise from the skin in much the same way. The insulating layer consists largely of two kinds of feathers termed filoplumes and down feathers which are not used in flight. They are smaller and much less complicated than are the larger feathers of the wings and tail. The feathers used in flight are strong and light and consist of a central axis bearing the barbs which form the vane. The barbs bear barbules, each of which is hooked and clings to the barbules of the adjoining barb so that no air can penetrate the vane.

When a bird is to be dissected or a chicken to be carved it is at once obvious that it differs in at least one respect from a mammal, for when the animal is laid on its back, it is difficult to get through the body wall on the underside. This is due to the fact that the breastbone has a big downwardly projecting flange called the keel (Fig. 294), to which are attached the large pectoral muscles (the breast of a chicken) which manipulate the wings. When once the breastbone has been removed, it is possible to admire the extremely compact manner in which the organs are stowed away inside the body cavity. The interior presents a somewhat silvery appearance due to the presence of a great deal of air inside definite air sacs which of course help to lighten the body. These air sacs have branches into many of the bones, which are therefore very light as well as strong. It is probable that the air sacs play a large part in drawing an adequate supply of air through the lungs during flight.

Both pairs of limbs are very considerably modified, and so are the girdles of bone which support them. Some of the tarsals are fused to the lower end of the tibia, forming the tibio-tarsus. The other tarsals are fused to the elongated metatarsals, forming the tarso-metatarsus. There are four toes, three of which oppose the

other, forming a perching mechanism. The fore limbs have been modified to a much greater extent to form the wings. Once again

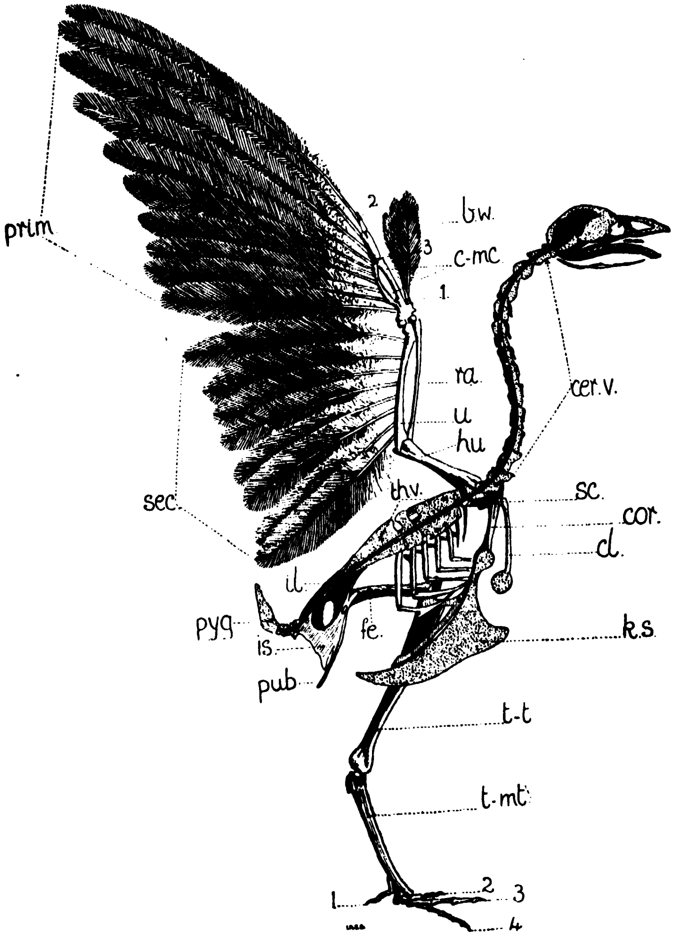


FIG. 294

Skeleton of bird. cer. v.—neck vertebræ ; ks—keel on sternum ; u—ulna ; tt—tibio-tarsus ; t.mt—tarso-metatarsus ; c.mc—carpo-metacarpus ; 1–4—digits ; cl—clavicle ; cor—coracord ; sc—scapula ; il—ilium ; is—ischium ; pub—pubis

the general plan is exactly the same as in mammals, but the wrist has been altered a good deal, and is not complete. Feathers are attached to the ulna, the ulna of the third metacarpal and to the

second and third fingers, the whole structure forming a fan, which is capable of extension at will.

Life Histories of Birds.—The life history of most birds is complicated by the perennial problem of migration. In this country something like half our birds are only resident for part of the year, and the majority of these are summer visitors. Nearly all our summer visitors migrate either singly or in large flocks to the north of Africa by a route which is fixed for each kind of bird. These facts have been discovered by tying small rings to the legs of captured birds and recording as much as possible their subsequent history on liberation. Such migrations raise numbers of fascinating and perplexing problems. How do they find their way? In some cases, it seems that the young birds do not undertake the journey alone, but in the company of older birds and, as it is well known that the senses of birds are very acute, it is reasonable to assume that, in some remarkable way, they are guided by landmarks of some kind, such as coast-lines, rivers and mountains. However, this cannot be regarded as finally proved, as they frequently seem to fly at great heights and for considerable distances across the sea. In the case of the cuckoo, it is known that the young birds frequently do undertake the journey in the absence of older birds.

The swallow provides a good example of a fairly simple case of migration. Swallows come to this country from the south during the first week of April, either singly or in pairs, and they continue to arrive until the middle of May, by which time they have become quite common over the whole country. Many of the earlier arrivals do not stay here but continue their journey to Scandinavia and Northern Europe, and these may be called birds of passage rather than summer migrants to this country. They come from regions south of the Sahara and follow the coasts of Spain and France on their journey of some 3,000 miles. The return journey is begun at the end of August and small parties including both young and old birds continue to leave throughout September and October. The return of the birds of passage from Northern Europe occurs during the latter part of this time and they mingle with the swallows and other birds from this country.

A final answer to the problem of the reason for these movements is very difficult to find. It is possible that migration began during successive Ice Ages when animals were forced farther and farther south by the ice. Intense competition for food may have played

some part in the distant past, but it seems more likely that the rhythm of migration is a breeding phenomenon. It has recently been suggested that there are two factors which determine the date of departure of the bird. The first is that the bird is very sensitive to the relative length of day and night and that a given ratio provides the signal for migration. The second factor is thought to be certain changes in the reproductive organs.

CHAPTER XLVIII

FOSSILS

FOSSILS (Fig. 295) are very common when one begins to hunt in quarries and cuttings for them. They are either portions of parts of ancient plants and animals which have literally become petrified or turned to stone over very long periods of time, or they are casts of such hard parts. Some of them are very easy to recognize as having belonged to a particular animal or plant, but in other cases a great deal of skill is needed. In exceptional circumstances, whole animals, such as mammoths, of comparatively recent date have been found preserved in ice in Siberia. Occasionally pieces of amber, which is derived from the resin of certain trees, has fossilized with insects actually inside it.

Sedimentary Rocks.—The explanation of the significance of fossils has been built up by supposing the natural forces and events of the past were of exactly the same nature as those in existence at the moment, and that it is thus possible to argue backwards. It is quite obvious to-day that land masses are being worn away by weathering, and that the sediment so formed must ultimately be deposited at the bottom of the sea. This suggests a method of origin of what are called sedimentary rocks such as sandstone, limestone and clay. Sedimentary rocks are found in horizontal layers (Fig. 296). The same layers are found in different quarries, cuttings and borings not only in this country but all over the world. The order of the layers among themselves is always the same, except that there is sometimes a gap. The layers are usually tilted, and different layers appear at the surface as outcrops. Thus one village may be on an outcrop of the Gault and a neighbouring village on Upper Greensand. The tilting is due to earth movements of various kinds, and there are also breaks known as faults at which slipping movements have occurred. It would seem that each horizontal layer of rock represents a period spent beneath the sea, a lake or a marsh. If so, there must have been many vertical

movements of land masses, as even in a single quarry there are very many horizontal layers. There are many indications that such

FIG. 295
A slab of sandstone covered with fossil fishes

movements are still taking place. In some parts of the world rocks obviously battered by the sea are now well above sea level, and in others steps which once led down to the sea are now well below low tide mark. These vertical movements are quite unex-

plained, but they show that the explanation given of the origin of the horizontal layers is correct.

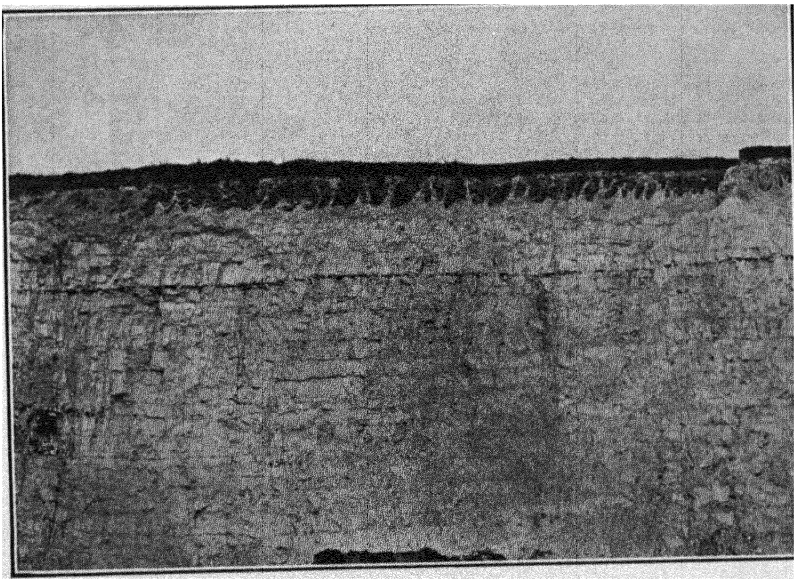


FIG. 296

Chalk exposed in cliffs of North Foreland, near Broadstairs, Kent

(*From "British Regional Geology: The Wealden District" (F. H. Edmunds), by permission of the Controller of H.M. Stationery Office*)

Geological Periods.—It may be presumed, therefore, that, in the majority of cases, fossils which are found in a particular layer of sediment must be parts of animals which lived in the period during which that sediment was being laid down under the sea. When the layers can be sorted out therefore, one ought to be able to obtain a good idea of the animal and plant life of successive eras. This has been worked out to a large extent during the last seventy years, and it is possible to get a very good idea of what has happened. A list of the sorted-out layers, and the names given to the periods during which they were formed, is given in Fig. 297. A rough estimate of the length of the periods is also given. It must be emphasized, however, that the fossil record is, and must always be, incomplete for the simple reason that little or no record is left

of organisms lacking any hard parts, and also that fossils are not formed unless the organism decays out of contact with the air and under certain conditions which are not likely to be fulfilled, except by accident, in the case of land animals.

Some rocks, such as granite, are not sedimentary, but have obviously been molten at some time or other. These are known as igneous rocks. Others, known as metamorphic rocks, have been molten and subjected during that time to great pressure. The oldest rocks in the earth's crust are of this type, and represent a vast period of time during which living organisms appeared on earth for the first time. During that time a great deal must have happened, for the first, i.e. the lowest, sedimentary rocks contain fossils of many kinds of quite highly organized invertebrate animals. Of course, in igneous rocks one cannot hope to find much in the way of fossils, so that any ideas which may be formed as to the origin of life have no solid foundation of fossil material, but are guesses made on other kinds of evidence.

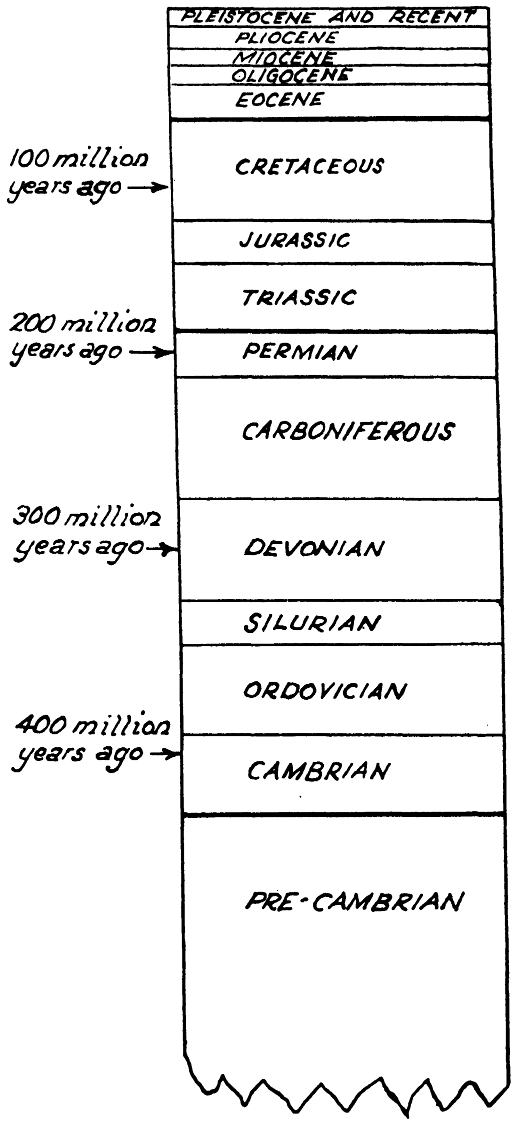


FIG. 297
Table of geological periods

The fossils of the period immediately following the Pre-Cambrian are all of marine animals, and it is fairly clear that there can have been no terrestrial life at that time. The fossils show that animals existed then which are related to our modern crustacea, scorpions, sea-lilies and cuttlefish. Some of these kinds of animals lasted a long time, especially the ammonites, which only disappeared finally at the end of the Permian. The next significant thing to happen is the appearance of creatures which were undoubtedly primitive fish in the Silurian. They gradually became more adapted to their environment, in short more like modern fish, and ultimately became the dominant organisms in the sea. In most cases, the story of the rise of a group of animals is that of a smallish unspecialized type, which acquires one or more all-important new features which give it a great advantage over the normal type. A great increase in number is the ultimate result, with such intense competition that many are forced to seek new places in which to live, leading to migration and colonization of new media, such as fresh water, dry land or even the air. After a time this race is supplanted by a later one which has some feature giving it a great advantage, and so the story goes on. Some of the supplanted types of organism, such as the dinosaurs, die out altogether, but others go on evolving new types, as the fish have done. The fish are very ancient as a race, but most of those which dominate the sea now are comparatively recent types.

Presumably, previous to the Devonian, there was some land above the surface of the sea, but it was probably unfit for living organisms. Certainly it is not until this period that there is any evidence of any life on land. The first animals to leave any record were a few fish which may have lived in marshes and swamps. In the Carboniferous there were many large terrestrial vertebrates, presumably descended from the fish. They were heavy-bodied and although they now had limbs instead of fins, they were quite unable to move about quickly. These animals are classified as amphibia, though they have little superficial resemblance to our modern frogs and newts.

At this point we must halt to summarize the corresponding history of plants. Seaweeds do not have hard parts, and one would not expect to find fossils of them. It is only when one comes to the Devonian that definite plant fossils are found. They resemble very simple ferns, but have leaves quite unlike those of ferns, and in many cases, no leaves at all. Fossils of many ferns

and related plants have been found from the Carboniferous and, in fact, most of the coal was formed during this period. These plants, which were very large and woody, died and became enveloped in the swampy ground in which the coal forests flourished. Coal is thus largely the fossilized remains of plants, and many traces of its origin, such as imprints of leaves, are commonly found in it. The most characteristic of all these coal trees was a big relative of our modern horsetails, some thirty to forty feet high and readily recognizable by means of the arrangement of the tiny leaves and lateral branches which are arranged in rings.

The typical vertebrate inhabitants of these forests were large amphibians, but the reptiles, distinguished from them by their scaly dry skins and their greater adaptation to land, now make their first appearance. They were descended from the amphibia and, by the end of the next period, they were so numerous that competition had forced them into many new environments, some, such as the ichthyosaurus, going back to the sea, pterodactyls trying to fly, while many, such as the carnivorous dinosaurs (Fig. 298) were beginning to move comparatively rapidly on land. These new animals were, on the whole, very successful, and they dominated animal life for millions of years until the end of the Mesozoic, which is truly called the Age of Reptiles.

There have been many suggestions for the comparatively sudden disappearance of the large reptiles, but an important reason must surely have been that these huge unwieldy creatures (Fig. 298) could simply not cope with the very much smaller, more active and more intelligent mammals which were beginning to appear. By the end of the Mesozoic, there were several groups of mammals, none of which has persisted to the present, but which were the ancestors of modern mammals. Birds, like mammals, are descended from reptiles, though, of course, from a different offshoot. There are, however, no really useful fossils to help to fill in the details, for the earliest bird fossils are quite definitely bird-like, though they have some reptilian features, such as teeth. Man is quite recent, having a fossil history of a few thousands of years, his evolution seeming to date from the ice ages of the Pleistocene. There are not many human fossils as man is a terrestrial animal, and the bones are not likely to fossilize under these conditions. The fossils which have been discovered reveal a transition from a skull with many ape-like characteristics, such as a protruding face and high cheek bones and a subhuman size of cranium, to the

modern type, though, once again, all these fossils seem to be of definite men and not of apes.

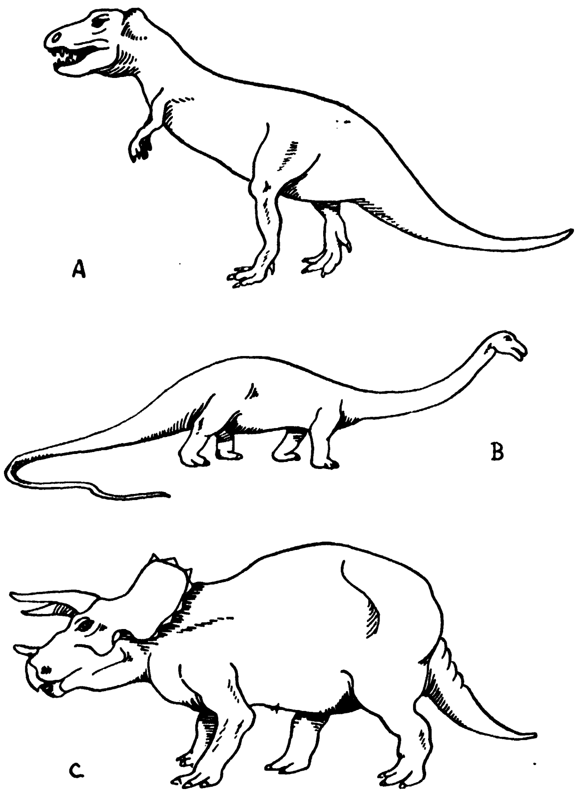


FIG. 298

Dinosaurs. A. Tyrannosaurus. (carnivorous, 47 feet long). B. Diplodocus (herbivorous, 87 feet long). C. Triceratops (herbivorous, 20–25 feet long)

(After Lull, "Organic Evolution," published by the MacMillan Co., New York)

Fossil Horses.—There are big gaps in the evolutionary picture of modern mammals, but in some cases, there are extraordinarily complete series of fossils, the chief examples being the horses, the elephants and the camels. Of these, the horse series is the most complete, the fossils having been worked out in America during the last forty years. All the above animals have many distinctive

features, and the series of fossils serves to show how these features have become more pronounced during the Tertiary period. The ancestor of the modern horse would not now be recognised as a horse at all, being a small animal about the size of a dog, with a more or less complete set of bones in its wrists and ankles. The intermediate types (Fig. 299) show the evolution of the cannon bone, in other words how the number of digits in each limb has

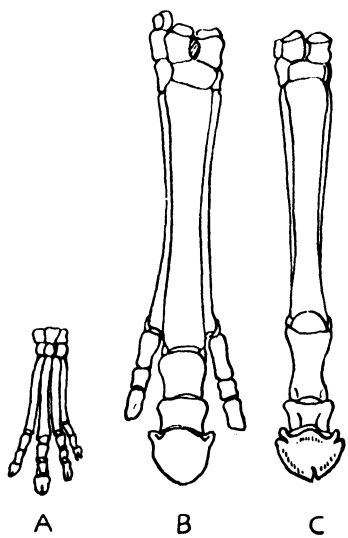


FIG. 299

Fore limbs of fossil horses. A. Eohippus (Œocene). B. Hypohippus (Miocene). C. Pliohippus (Pliocene). All $\frac{1}{6}$ natural size

(After Lull, "Organic Evolution," published by the MacMillan Co., New York)

become reduced to one elongated bone, a very effective modification for greater speed. The other chief changes are increase in size of the whole body, and increase in depth and complexity of the cheek teeth, especially the pre-molars. The fossils make it clear that North America was the region in which the horse evolved, though, surprisingly enough, the last stages were carried out in Europe, and the modern horse reintroduced into North America.

CHAPTER XLIX

EVOLUTION

WHEN Linnæus produced his scheme of classification of animals and plants towards the end of the eighteenth century, he took it for granted that every species had existed in its present form since its creation. Such was the current belief of the time, though the possibility of change and, in fact, of a common origin of organisms had been discussed, notably by the Greeks. It was not until the century preceding the work of Charles Darwin that the matter was seriously considered again. Thus Darwin was by no means the first person to suggest the idea of progressive changes in organisms which is termed evolution, but he was the first person to marshal a large body of evidence in its favour and to suggest a very plausible method by which it might have happened. This chapter will include a brief review of the type of evidence on which modern views about evolution are based.

Firstly, there is a certain basic similarity between all organisms. Whatever their nature and structure, the scope of their activities is always roughly the same. The requirements of protoplasm in all cases seem to be very largely the same, and there is no initial difficulty which might rule out the possibility of unbridgeable gaps between different groups of organisms. The study of anatomy, far from revealing gaps of this nature, shows that in any group of organisms there is a fairly continuous series of changes which suggest very strongly that the series represents stages in the history of the group. Thus, in the vertebrates a study of the heart and circulatory system, the brain and nervous system, the skeleton and, in fact, all the systems of a fish, a frog, a lizard and a mammal, show a progressive development in such a way that it is impossible not to think that it represents a historical sequence. Thus, to quote one example only, the heart of a fish has one auricle and one ventricle, a frog has two auricles and one ventricle, while in the lizard the ventricle is half divided. In the crocodile, another

reptile, the division is complete except for a small hole between the ventricles, while both birds and mammals have two auricles and two ventricles. The nervous system has advanced in a similar way, the cerebral part of the brain becoming steadily larger until, in the mammal, it is so large that it dwarfs the other parts. At the same time, other organs show little or no change throughout the series, so that the basic similarity of these types is still very clear. Thus, the eye is very constant in structure throughout the vertebrates. A comparative study of the skeleton of the fore limb of a frog, a bird, a bat and a mole show very conclusively that all are built on the same basic plan, but are modified for very different purposes in the animals mentioned. This type of study also reveals in many animals the existence of primitive or vestigial structures, which cannot but be the remnants of organs that were once in active use but which have now degenerated. Thus there are traces in the front leg of the horse of the second and fourth digits which have not completely disappeared. It will be remembered that the horse runs on the tip of its middle finger and toe, the other four digits in each limb having largely disappeared. There are some seventy or so vestigial structures in the human body, one of them being the relic of the tail--the coccyx—at the base of the spine.

This kind of evidence becomes practically irrefutable when supported by the evidence from fossils. The nature of fossils has been explained in a previous chapter, and the really important point here is that fossils from successive strata show a gradual series of changes over long periods of time, and in some fairly complete series of fossils, as in those showing the development of the peculiar structure of the limbs of a horse or the skull and teeth of the elephant, it is possible to see the exact way in which a particular structure has evolved. Fossils show quite clearly that the supposition that the fish, the amphibian, the reptile and the mammal represent a historical sequence is completely justified. Thus, fish make their first appearance in the Silurian, amphibia in the Devonian, reptiles in the Carboniferous and mammals do not become abundant until the Cretaceous. Yet another kind of evidence is admissible in support of this argument. A study of the early stages of all vertebrates reveals that these stages are startlingly similar. All vertebrates pass through a stage in which many features closely resemble those of fish. The tadpole, for instance, has first external and then true internal gills with a

completely fishlike circulatory stem and many other resemblances to fish. Reptilian, bird and mammal embryos all pass through a stage in which they have gill-slits, though they are not here functional.

The vertebrates form a very convenient series of animals to illustrate the above points, but these can be illustrated from all groups of plants and animals. It is obviously easier to trace fairly short series than to trace all the groups back to a common ancestor, and there are, as might be expected, many gaps which present difficult problems. However, practically all the available evidence seems to point to the conclusion outlined above. The argument may be pursued on other than anatomical grounds. The geographical distribution of many animals and plants presents problems which are insoluble except on evolutionary grounds. One such problem is the fact that the mammals found in Australia previous to the introduction of rabbits belong to a group representing an earlier stage in mammalian evolution—namely the marsupials, including the kangaroo, wombat and opossum. Now fossils of marsupials are found over practically the whole of the mainland of Europe and Asia, and it seems reasonable to suppose that Australia became detached from the mainland at a period when the mammals had only reached the marsupial stage. On the mainland the later type was evolved, became numerous and spread, but did not reach Australia because it was divided off by an impassable sea barrier.

In other ways, too, the evolution hypothesis seems to be justified. If each species was specially created, one might expect that the individual members would be much more similar than they are in fact. Actually individuals of the same species vary a great deal. There may be purely chance variations which are not inherited. For instance, a graph in which human stature is plotted against a number of individuals will be of the form shown. The height of the greatest number of individuals lies midway between the two extremes. Such a graph (Fig. 300) shows that the factor in question is a matter of chance, though in this particular case the potentiality of reaching a definite height is inherited and is not a matter of chance. There are, however, other ways in which individuals vary. Thus in man, colour blindness and eye colour are known to be inherited and this type of variation seems to be much more deeply seated. The origin of such conditions is, in fact, due to changes of various kinds in the nuclear material of the individual

concerned, and must therefore be inherited. Such a change is termed a mutation, and there are multitudes of examples of such changes in all types of animals and plants, arising suddenly in the first place and then being perpetuated. A third type of variation is that acquired by the individual during its own lifetime. Such changes as the developed musculature of the athlete or manual worker come under this heading, and it is very doubtful if they can be inherited.

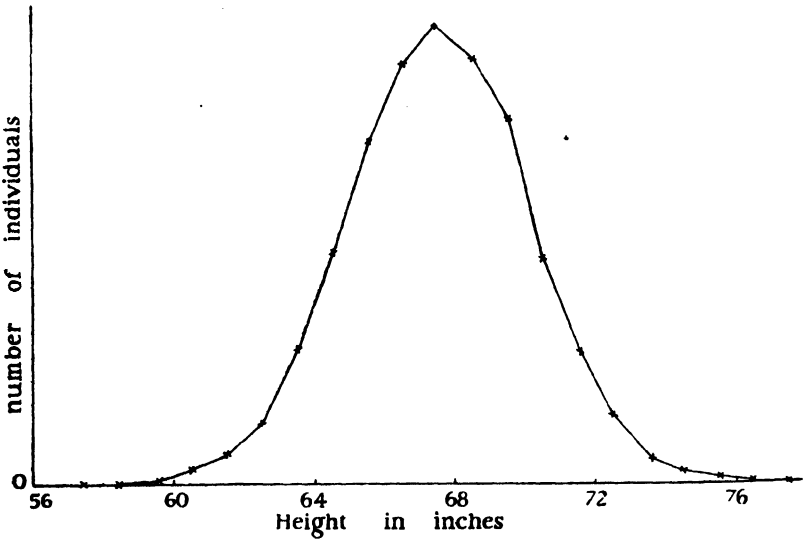


FIG. 300

Human height

(*After Yule. "Theory of Statistics," published by Messrs. Charles Griffin & Co., Ltd.*)

A further pointer to the possibility of evolution having taken place is that cultivated plants and domesticated animals have, in the course of centuries, become very different from their wild relatives. These changes are due to selective breeding by man, and to deliberate changes in their environment. A constant stream of new varieties of plants and animals is being brought into existence by plant- and stock-breeders by these methods. The point here is that changes in organisms over long or even comparatively short periods of time are possible though, in the particular case under discussion, it must be admitted that they have

been produced artificially. Change is, however, clearly possible, as can clearly be seen in, for example, the varieties of the pigeon, all of which have arisen from the wild rock dove. All the varieties of dogs, rabbits, budgerigars, goldfish, and other animals, provide further examples.

Natural Selection.—These arguments are those originally advanced by Charles Darwin, published in the *Origin of Species* which appeared in 1859. Since then, of course, a vast amount of knowledge of the same kind has been accumulated. But Darwin did not stop here as he also brought forward a very reasonable theory as to how evolution might have taken place. He was much influenced by a paper written towards the close of the eighteenth century by the Rev. J. R. Malthus, pointing out that the ideals of a school of political theorists, who looked upon the industrial revolution as a step towards a democratic utopia, completely ignored the fact that the population was increasing at a much greater rate than food could be produced for them, and that such checks as war and disease were necessary to keep the situation in hand. Darwin realized very clearly that this doctrine, whether or not applicable to human society, represented very clearly what happened in nature. Reflection shows that the numbers of offspring produced by organisms are comparatively vast, and that only a few can hope to survive. Thus, of the millions of eggs produced by a cod, only a half-dozen or so will reach maturity. Such a state of affairs produces a "struggle for existence" among organisms, with the result that many are eliminated. Darwin thought that those which remained would do so because they were better adapted to survive than those killed off. He thought that, of all the random variations among organisms of the same species, some gave the possessors the advantage in the struggle for existence and that those which survived were those best fitted to do so. This train of thought led to the expressions "survival of the fittest" and "selection by nature" or, as it is usually termed, "natural selection." Darwin's theory was, thus, that variation was purely random and that some variations survived owing to the fact that they gave their possessors an advantage over other members of the species without them, while others were quite useless and failed to survive at all. New structures, he thought, came into existence in this way, and in this way organisms evolved from simple organisms, possibly all from a common ancestor. This theory is the essence of Darwinism, not the crude application of

the idea expressed in the phrase " we are derived from monkeys." Actually, if the skeleton of an ape and a man are examined, it will be seen that, in principle and in most of the details, they are identical, even down to the dental formula. In this case, the best way to express the undoubted relationship is to say that modern monkeys, apes and man have all sprung from a common ancestor.

Since Darwin's own day, it has been conclusively shown that the random variations on which part of his theory of the mechanism of evolution was based are not inherited and thus the Darwinian theory in its original form is untenable. If, however, the inherited type of variation, termed the mutation, is substituted for random variation, we have the method by which it is now thought that evolution has taken place.

QUESTIONS

C. = Cambridge University School Certificate.
L. = London University General School Examination.
N.U. = Northern Universities J.M.B. School Certificate.
O. = Oxford University School Certificate.
O.C. = Oxford and Cambridge School Certificate.

1. (i) Distinguish between *work* and *power* and state the units in which each is usually measured. (ii) A motor-car weighing 15 cwt. travels up an incline of 1 in 10 at a uniform speed of 15 miles per hour. Assuming there is no frictional resistance of any kind, calculate the horse-power at which the car is working. N.U.

2. In order to raise a load of 2,000 lb. through a distance of 6 ft. by means of a crane, a man finds that he must exert a force of 50 lb. through a distance of 480 ft. Find the Mechanical Advantage, the Velocity Ratio, and the Efficiency of the crane. If the Mechanical Equivalent of heat is 778 ft.lb. per British Thermal Unit, how much heat will be generated in the crane by friction ? N.U.

3. What do you understand by the *law of the lever* ? Draw diagrams of *three* of the following household appliances, which depend upon the principle of the lever :

(*a*) Sugar-tongs.
(*b*) Can-opener.
(*c*) Nut-crackers.
(*d*) Pliers.

For each utensil, explain whether the force produced is greater or less than the force exerted. L.

4. Why is it possible to describe a lever as a machine ? Give an account of the various types of lever in common use.

A pair of pliers is used to cut a piece of wire placed 0·5 in. from the rivet. In order to cut the wire, a force of 7 lb. exerted on each of the handles by the fingers 4 in. from the rivet is just sufficient. What is the resistance to cutting offered by the wire ? O.C.

5. Describe with a diagram a simple pulley system in which the effort moves four times as fast as the load. What effort will be required to lift 72 lb. if the system is 60 per cent. efficient ? C.

6. A rectangular log 4 ft. long, 2 ft. wide and 18 in. high weighs 600 lb. Show that it will float in sea-water of density 64 lb. per

cubic foot, and find the least weight which must be placed on the top of the log in order to sink it in the sea-water. L.

7. Describe with the aid of diagrams a pump which would raise water from a level 15 ft. below the ground and deliver it to the top of a house 40 ft. high. Calculate the horse-power required to work the pump if it fills a 500-gallon tank in 20 minutes, assuming that there is no waste of energy. (1 gallon of water weighs 10 lb.; 1 h.p. = 33,000 ft.-lb. per min.) C.

8. Although steel is denser than water it is possible to cause a fine bright sewing-needle to float on water. Why is this possible? N.U.

9. What experiments would you do to show that air exerts pressure in all directions? O.

10. Describe, with a diagram, the construction and working of a simple form of steam-engine. Indicate the ways in which the greater part of the energy of the fuel is wasted. O.C.

11. Answer *two* of the following:

(*a*) A silver tube containing ether can be cooled by bubbling air through the ether. Explain this. On two different days the atmospheric temperature is 15° C.; on one day dew forms on the outside of the tube when the temperature of the ether is 12° C., but on the other dew does not form until the temperature of the ether has been reduced to 5° C. Explain why dew is formed at different temperatures on the two days.

(*b*) Two similar hot-water bottles, of 2,000 c.c. capacity, are filled at 95° C., one with water, the other with a liquid whose density is 1·2 gm. per c.c. and specific heat 0·5. State, with reasons, which will be the more effective "warmer."

(*c*) You have two similar copper pots, the outside of one is polished, the other is coated with lampblack. The pots contain equal quantities of water at 80° C. and are placed on cork on a table in a room. Will the temperatures fall at the same rate in both pots? Give reasons.

When the temperatures have fallen to that of the room, the pots are placed in front of a bright fire. Will the temperatures rise at the same rate in both pots? Again give reasons. C.

12. An iron pipe is 200 ft. long at 0° C. How much longer will it be when steam at 100° C. is passing through it, if the coefficient of expansion of iron is 0·000012 per deg. C.? C.

13. Explain shortly the reasons for any *three* of the following:

(*a*) The breaking of a cold and thick glass vessel when boiling water is poured into it.

(*b*) The chilling effect of wet clothes.

(*c*) The action of a vacuum flask in keeping liquids hot.

(*d*) A frosty night is usually a clear one. O.

14. Describe a small gas-fire suitable for heating a bedroom and explain the scientific principles underlying its construction.

State briefly the advantages and disadvantages in using a gas-fire for such a purpose. L.

15. What is the British Thermal Unit? A therm = 100,000 B.Th.U. What is the cost of heating the water for a 50-gallon bath from 40° F. to 80° F. with gas at 10*d*. per therm? 1 gallon of water = 10 lb. C.

16. Describe briefly the construction and action of a clinical (doctor's) thermometer.

What precautions are necessary in using it and in cleaning it?

What is the temperature of the blood of a person in good health? L.

17. Name and define the unit in which *quantity of heat* is measured.

Show that if 40 grams of water at 70° C. is mixed with 120 grams of water at 10° C., the final resulting temperature is 25° C. (neglecting loss of heat). L.

18. The calorific value of coal-gas is 500 British Thermal Units per cubic foot. What volume of gas would be required to boil 1 qt. ($2\frac{1}{2}$ lb.) of water originally at a temperature of 40° F. if the efficiency of the heater is 25 per cent.? N.U.

19. If a hot-water bottle be wrapped in flannel it retains its heat much longer than when not so covered. On the other hand if, in summer weather, I wish to prevent a lump of ice from melting quickly, I may wrap it in several layers of flannel. Account for these apparently contradictory statements. N.U.

20. How do the physical properties of air affect the problem of ventilation? Explain, with the aid of diagrams, how a living-room could be planned to give satisfactory heating and ventilation. L.

21. If we are to cook food by boiling, can we materially shorten the time of cooking by using a hotter fire after the boiling has begun? Give a reason for your answer. N.U.

22. How could you take a photograph without a lens? Upon what property of light does your method depend? What is the disadvantage of this method? C.

23. Show, by means of a carefully drawn diagram, how, by employing an arrangement of mirrors, it is possible for a lady to obtain a back view of a hat she is wearing. N.U.

24. Describe an experiment which demonstrates *one* important difference between the propagation of sound and light.

State the approximate velocities of sound and of light in air, and mention two instances in which the difference in these velocities is clearly shown. L.

25. Explain *three* of the following:

(*a*) Short sight.

(*b*) Umbra and penumbra.

(*c*) Green paint is made by mixing blue and yellow paints.

(*d*) Ponds appear to be shallower than they really are. O.C.

26. Explain, giving diagrams, what may happen to a beam of light that falls on the face of a triangular glass prism.

Glass prisms are sometimes fixed in the pavement outside houses in order to illuminate underground rooms. Explain how this device works. O.C.

27. With the aid of careful diagrams showing how the images are formed, describe the action of *two* of the following: a looking-glass, a magnifying-glass, a telescope, a periscope, a kaleidoscope. (Rays should be drawn if possible from more than one point of the object, and the approximate position of the eye should be shown in the diagrams.) C.

28. What is a *converging* lens? Give a simple account of its action and point out two different uses of such a lens. L.

29. Explain why there is usually an appreciable interval of time between observing a flash of lightning and hearing the thunder.

Account for the rolling sound which is often produced when thunder is heard. L.

30. A trade poster consists of letters printed, some in green and others in red, on a white background. Describe and explain the effect of illuminating it with (*a*) green light, (*b*) red light, (*c*) both lights at once.

Why should the compass on a modern warship be more liable to error than the compass on a warship in the time of Nelson? Describe how such errors can be minimized. C.

31. Explain the production of an *Echo*. How can this principle be used, during a fog, to estimate the distance of a ship from the shore if the latter is bounded by high cliffs? L.

32. Describe *three* ways of producing a musical note. What is meant by the "pitch" of a note? How is the pitch of the note controlled in each of the ways of note-production you describe? O.C.

33. Describe briefly the process involved in the production and reception of a note which is sung by one person and heard by another who is a short distance away. What determines (*a*) the pitch of the note, (*b*) the loudness of the note? L.

34. What is meant by a "line of magnetic force"? How may its properties be used to explain some of the important facts of magnetism? O.C.

35. Describe carefully how you could magnetize a steel knitting-needle AB so that the end A may become N. seeking. State what new properties the needle possesses after it has been magnetized. L.

36. Describe and explain the mode of action of some machine or instrument in which electrical energy is used to produce motion of some kind. O.C.

37. What reasons would you give for advising a person not to connect a large electric radiator on to a lighting circuit?

How much would it cost to keep an electric radiator going for two

hours if it took a current of 6 amps. when connected to a 200-volt circuit? 1 kilowatt-hour costs 5*d.*

If the radiator consists of two similar heating coils, show how they should be connected so that one coil can be switched off when desired. Calculate the resistance of each coil. C.

38. Describe and explain the function of a *fuse* in a typical household electrical installation. With the aid of a diagram, explain the relation between sub-circuit fuses and the main fuse in such an installation. L.

39. (*a*) With the aid of a sketch describe briefly the construction of an accumulator. (*b*) What changes take place on charge and discharge (i) in the density of the acid, and (ii) in the colour of the plates? (*c*) What is meant by the statement that the capacity of a certain accumulator is 50 ampere hours? N.U.

40. What is polarization? How does it affect the utility of a Leclanché cell? C.

41. Explain how it is possible to run an electric motor as a dynamo.

An electric motor takes 10 amps. at 200 volts to drive a dynamo producing current at 300 volts. What is the maximum current that could be taken from the dynamo? Why is the value you calculate a maximum one? O.C.

42. Give a short account of one practical use of each of the following effects of an electric current (*a*) magnetic, (*b*) thermal, (*c*) electrolytic.

43. Name two methods in common use to prevent sheet iron from rusting. N.U.

44. Describe and explain what you would observe on heating a mixture of iron filings and sulphur in a test-tube. Compare the action of (*a*) dilute hydrochloric acid, (*b*) carbon bisulphide, on the contents of the tube before and after heating. L.

45. What are the properties of zinc and iron which lead us to classify them as *metals*. What do you know of the reaction which can occur between iron and steam? O.

46. What happens when solid calcium chloride is exposed to the atmosphere? Name any common compound used in the kitchen which is also affected by the atmosphere. N.U.

47. The insides of kettles are often found to be coated with a whitish deposit called *fur*. Why is this? Mention shortly *two* ways in which you could show the chemical nature of this deposit. O.

48. Describe the preparation from common salt (sodium chloride) of any substance of importance in chemistry or in everyday life, and give an account of its properties. O.C.

49. Write down the names and formulæ of two substances in each of the following classes: *Acids, bases* and *salts*. Describe in detail how you could prepare a salt from an acid and a base which you have selected. L.

50. How would you demonstrate the presence in air of (*a*) carbon dioxide, (*b*) water-vapour ?

Name *three* other gases which are present in air.

Outline a process by which oxygen can be obtained from air.

Many tons of oxygen are manufactured annually. For what purposes is the gas used ? C.

51. Describe, in detail, the action of water on each of the following metals : (*a*) sodium ; (*b*) calcium ; (*c*) iron. L.

52. Describe and explain the burning of (*a*) coal-gas, (*b*) paraffin, (*c*) coke, under conditions involving (1) partial combustion, (2) complete combustion. N.U.

53. What do you understand by " the chemical effect of electricity " ? Describe one good experiment to illustrate this effect, and give such explanation as you think necessary for a proper understanding of the experiment. L.

54. What are the general properties of acids ?

Describe the action of hydrochloric acid on each of the following : (*a*) marble ; (*b*) ammonia ; (*c*) manganese dioxide. L.

55. Compare the following as sources of water for domestic use : (*a*) rain ; (*b*) a spring in chalk ; (*c*) a shallow well.

Describe an experiment by which the *hardness* of a natural water can be estimated. L.

56. Describe carefully all you would observe if small quantities of the following substances were carefully heated separately in test-tubes : (*a*) potassium chlorate ; (*b*) dried leaf powder ; (*c*) washing soda ; (*d*) a mixture of ammonium sulphate and slaked lime. N.U.

57. How would you prove that the atmosphere contains carbon dioxide ? State the properties of this gas, and point out any useful purpose served by its presence in the atmosphere. O.

58. Name the chief constituents of the atmosphere and give a brief account of the part played by each in everyday life. L.

59. Illustrate *three* methods by which salts can be prepared. Explain the uses in everyday life or in industry of any *one* salt. O.C.

60. Write down the names and formulæ of two gases which possess bleaching properties.

Describe the preparation of *one* of these gases and account for its bleaching action. L.

61. Name the more important constituents of coal-gas. To which of these constituents is the illuminating power of coal-gas due ? Describe how you would show experimentally two of the substances which are formed when coal-gas is burnt in the ordinary gas flame. L.

62. Name two common substances, which when heated together, react on each other with the liberation of ammonia. Describe two simple tests you could apply to satisfy yourself that the gas evolved was ammonia. N.U.

63. In what organs may food be stored in a plant ? Illustrate by drawings the storage organs in any four of the following plants and say in what part of each plant the food is stored : carrot, wheat, onion, crocus, artichoke, bean. O.

64. Describe the methods adopted to survive the unfavourable season (in England, winter) in two animal and two plant examples chosen as widely as possible. C.

65. Describe carefully with the aid of sketches two ways of telling the age of a twig or branch of a tree. N.U.

66. What are the most abundant food substances in (1) meat, (2) butter and (3) bread, and how are these substances changed by digestion ? O.C.

67. Make a drawing of the jaws of a dog or of a man showing the teeth, and explain the functions of each kind of tooth. O.C.

68. An animal eats a meal of fat meat and biscuit. Explain what happens to the meal as it passes through the alimentary canal of the animal. N.U.

69. What is a gland ? Show by means of drawings the positions of two glands in the body of an animal and explain their functions. O.C.

70. Write a brief description of blood and its functions. What advantages do higher animals gain by having warm blood, and how is the temperature regulated ? L.

71. Make a diagram to show the circulation of the blood from the right auricle until it leaves the left ventricle. Describe the changes which occur in the blood during this part of the circulation. L.

72. Of what importance is osmosis in plant life ? Describe *one* experiment which shows that this process takes place in a plant. O.

73. (*a*) Describe how you would proceed to test a green leaf for starch. (*b*) State how you would use this starch test to show that starch is produced only (i) when chlorophyll is present, (ii) in the presence of light. N.U.

74. Describe how oxygen is taken in and carried to the region in which it is used in (1) a named plant, (2) a named vertebrate animal. C.

75. Why is respiration an essential process in the metabolism of all living things ? Describe experiments designed to show that respiration is essentially the same in plants and animals. What is the advantage of special respiratory organs ? L.

76. What part does nitrogen play in the physiology of (*a*) animals, (*b*) plants ? Explain how nitrogen is obtained in both cases. L.

77. Give a concise account of the importance of water in the life of (*a*) animals, (*b*) plants. Select an example from plants and show how water is obtained. L.

78. Describe the function of muscles and nerves. Illustrate your answer by reference to a limb. L.

79. Give a brief account of the skeleton (excluding the skull) of a vertebrate animal. O.C.

80. Heat is a form of energy and energy cannot be created. Trace by careful steps as far back as you can the source of the energy that enables you to maintain your body temperature. C.

81. Describe the position of the spinal cord. Construct a diagram to show the structures given off at repeated intervals from the spinal cord. Explain the function of these structures. L.

82. What is meant by a " reflex action " ? Give two examples of reflex action as it may be observed in your own body. Explain with simple diagrams the structures essential for one of the actions. L.

83. Make a carefully labelled diagram to show the relative portions of the more important structures contained in the eye. When the visual gaze shifts from a distant to a near object explain what happens to (*a*) the pupil, (*b*) the lens. L.

84. Explain briefly the way in which the brain becomes conscious of a sound, and construct a diagram to show the various structures involved in the transmission. Why is it important that a free communication should exist between the throat and the ear ? L.

85. Give concise accounts of *two* experiments designed to illustrate the movements which take place in response to external influences, (*a*) in the growing region of a plant, (*b*) in any animal. L.

86. Give an account of the characters which distinguish all living matter from non-living matter, illustrating your answer by reference to Amœba or any other organism which you have studied. L.

87. Describe the life history of any one named insect, making fully labelled drawings of all the stages. Compare this life history with that of the frog. C.

88. What do you understand by the term pollination ? Describe with the aid of drawings how pollination is brought about in any one flower. C.

89. Give a general account of the way in which fruits and seeds are dispersed. Make outline drawings of two named fruits which provide examples of two of the ways you mention. C.

90. What is meant by fertilization ? Illustrate your answer by details of a definite example among (*a*) plants, (*b*) animals. Compare the products of fertilization in the two cases. L.

91. Describe the essential nature of sexual reproduction in animals and plants. O.C.

92. What is meant by " asexual reproduction " ? Describe the way in which reproduction takes place asexually in some (*a*) plant, (*b*) animal which you have studied. What is the (*a*) advantage, (*b*) disadvantage of this method of reproduction ? O.

93. Describe the germination of any *one* seed. What are the conditions necessary for its germination ? O.C.

94. Select any one plant or animal you have studied, and set down briefly your four main reasons for thinking that it is specially adapted to survive under the conditions in which it normally lives. Your answer should be illustrated by sketches. N.U.

95. What is meant by putrefaction ? O.C.

96. Give an account of yeast fermentation. What difference does the presence or absence of oxygen make to the process ? O.C.

97. In what way may human diseases be spread by animals ? O.C.

98. Either : How is the balance of nature preserved in the English countryside ? or : What is a parasite ? Describe the life history of one parasitic animal and one parasitic plant. O.C.

99. What factors lead to the accumulation of sediments on the sea floor ? O.C.

100. What are fossils and what can we learn from them ? O.C.

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